MAY 1957

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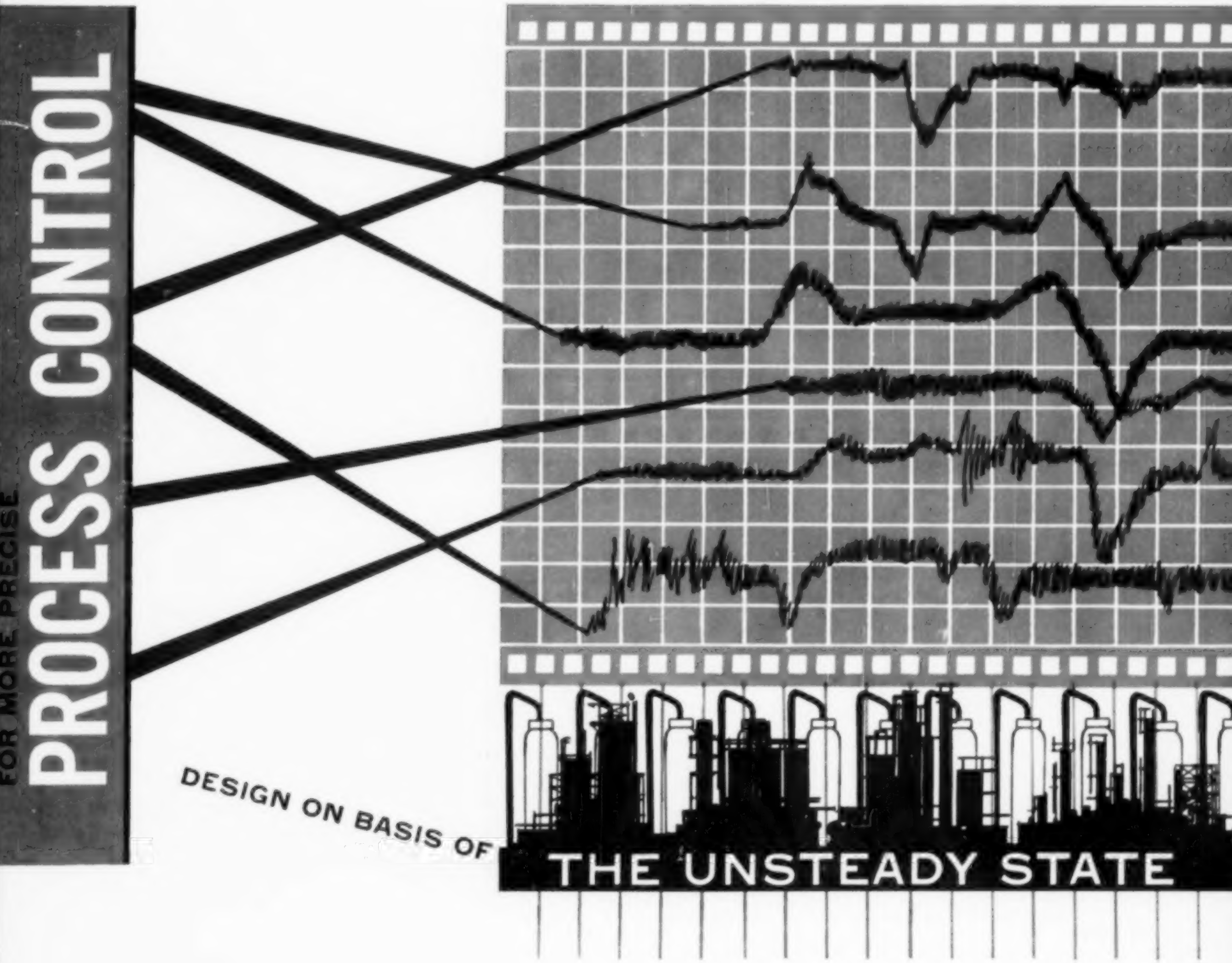
CHEMICAL ENGINEERING PROGRESS



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Chemical Engineering Progress

what's in this issue

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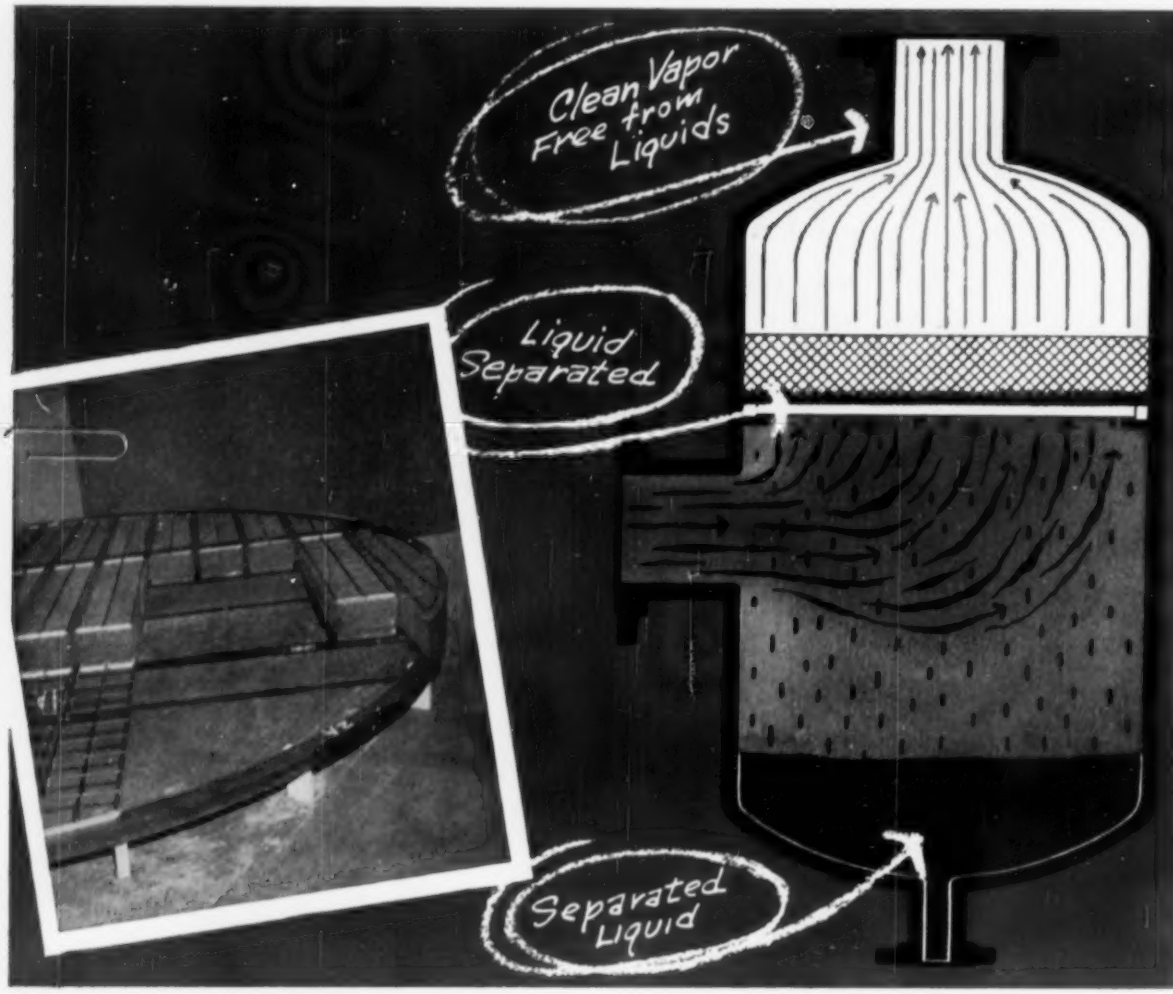
departmental features



Clean Vapor Free from Liquids
Liquid Separated
Separated Liquid

CEP

what's in this issue

(Continued from page 3)

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Cover by Milton Wynne Associates


Back in 1942 the new synthetic rubber program was of urgent importance to the war effort. Naugatuck Chemical Company, Division of U.S. Rubber Co., developed processes that included fluid mixing applications. Many of Naugatuck's top-entering and portable mixers were engineered and manufactured by Eastern Industries specifically for these processes.
After fourteen years of hard, continuous service, these Eastern Mixers continue proving their built-in reliability.
If you have a process entailing critical operating conditions, get a long-term guarantee on your investment by selecting durable Eastern Mixers. Eastern offers engineering assistance in the selection of proper mixers from the complete Eastern line.
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PORTABLE MIXERS
Various models offer a choice of speeds and H.P. dependent upon the consistencies of fluids. All models are available with shafts and propellers of various alloys. Single and dual propellers, and a wide choice of motors give flexibility to handle the most critical of operating conditions.
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Heavy-duty models cover the range from ¼ to 30 H.P., at speeds from 280 to 1725 R.P.M. Versatile in design . . . rugged in performance, these mixers offer a wide choice in mounting arrangements and motors. All side entering models are available with stuffing boxes which can be repacked with a full tank.
TURBINE MIXERS
Many of the Eastern Turbine applications include blending, dissolving and heat transfer. A variety of motor mounts and stuffing boxes available within a H.P. range of ¼ to 40, add flexibility to the Eastern line.

Noted and quoted *(from White Sulphur)*

PROCESSING TECHNIQUES OF THE FUTURE

Austin S. Brunjes | The Lummus Company, New York, N. Y.

A new process has been developed and is presently in the pilot plant stage for the production of acetylene at extremely high temperature. It has been estimated that acetylene so produced will cost considerably less than it does now. Other similar processes will be developed using the same fundamental basic reaction to produce other building blocks in the organic field.

Solar energy on a small scale is being used to produce oxides of nitrogen from air which in turn are made into fertilizer. A. D. Little has recently announced the completion of a solar furnace for experimental purposes, and the French have been operating experimental high temperature units for some time.

Some reactions take place at temperatures that melt and volatilize refractories. Both reactants and products are completely ionized. By creating a magnetic field at the wall of the vessel, the hot molecules are repelled thereby allowing the wall and refractory to remain at much lower temperatures. Such reactors are called "magneto-strictive" or magnetic jugs, and offer commercial possibilities for producing reactions requiring extremely high activation energies for short periods.

Many reactions favored thermodynamically by higher pressures have been uneconomical in the past because of the cost of pressure vessels to contain the reaction. A recent mechanical engineering paper has demonstrated the applicability of the constant shear theory to the design of pressure vessel heads and closures, permitting higher pressures with thinner materials.

New Construction Materials

Only recently 0.2 per cent of one of the less usual elements was added to stainless steel; the tensile strength was nearly doubled and the resistance to creep at high temperature was considerably improved. Science is beginning to go back and study the elements it has available, and how they affect one another in solid solution to form better alloys. This progress is an offshoot of the renascence of the chemistry of the solid state.

Armour Institute researchers, starting with a study of porcelainized and glass coated steel panels, concluded that a really successful ceramic coating which would resist temperature and oxidation would be a metal oxide itself; the oxide to survive the high temperatures and erosion and to insulate the metal, and the metal to give the necessary structural and tensile strength. Using a tool already developed, the metallizing gun, Armour found that this technique was not good enough to make a metal oxide bond to the metal. The oxide particles did not get hot enough to make a satisfactory bond. An entirely new technique and a new tool have been developed to spray these "flame ceramics" as coatings on metals and, although many have been made, few have been tested outside the laboratory. For instance, a zirconium oxide has been developed which does not soften at 2,500° C. (4,530° F.). Herein lies one of the keys to high temperature chemical processing vessels of the future.

We are all aware of the usefulness of graphite as a material of construction for many chemical reactions. A new process that looks very promising for the future has been developed for pressure moulding graphite. The tensile strength of the product is claimed to be three times that of cast iron at high temperatures. This material will not only be useful for reaction vessels, but may also be moulded into panels for various other types of construction where strength, insulation, and heat resistance are important criteria.

New Raw Materials

It was recently announced that "natural" rubber has been synthesized. Synthetic polyisoprene as normally prepared possesses an irregular structure which prevents it from having the great mechanical strength of natural rubber. Natural rubber has long been known as a linear polyisoprene. The secret of producing well-ordered polymers lies in the discovery and use of new catalysts and new catalyst families. The polymer revolution has already added several new words to our chemical language, namely "Atactic," "Isotactic," "Syndiotactic," and "Stereospecific."

These polymers yield x-ray diagrams indicating that they are highly crystalline. This means that they have higher melting points, are tougher and more rigid than the presently available forms. They may be drawn into oriented fibres which have a much higher tensile strength than nylon. It should be mentioned that not all isotactic polymers will be crystalline in spite of the regularity of structure, and not all atactic polymers are amorphous. Isotactic polypropylene is now being piloted in Italy. American companies are studying its potential. Because of its properties it will enter the same end use field as the various polyethylenes: film, mouldings, pipe, plastic bottles, and wire cable insulation. It also has other potential uses if low water absorption can be overcome, by entering the synthetic fiber field. In the nonapparel field it can be used for rope, industrial filter cloths, seat covers, and upholstery fabrics.

The catalysts so far used have been boron trifluoride complexes, Zeigler catalysts, one type of which is prepared by reacting $TiCl_4$ with $Al(Alkyl)_3$, the "Alfin" catalyst, and earlier the solid catalysts such as the molybdena on alumina, and the chromia-alumina-

(Continued on page 12)

This Age of Science

. . . This age of science in which we now live is capable of producing great good or even greater evil, depending upon the uses to which knowledge is put. Both atomic energy and electronics can be either a boon or a scourge to mankind. Which they are to be will depend very largely upon the educational forces of the world. If the educational institutions are devoted to the search for truth, and if dedicated scholars are permitted to ascertain and teach the truth as they understand it, instead of being oriented toward the invention of weapons of destruction in a race of armaments, untold blessings can flow from each of them. . . It will be done in America because our rights of belief and expression are guaranteed by the Constitution and because our concept of higher education is deeply rooted in the cause of freedom.

. . . It is in such times that there are no limits to human accomplishment. I believe without reservation that the college students of today have greater opportunities for accomplishing worthwhile things and of earning lasting satisfactions than did any other generation of Americans in our history.

Hon. Earl Warren on the occasion of the one hundredth anniversary of the establishment of Niagara University.

How to evaluate materials of construction for the chemical plant

Choosing materials of construction for chemical-industry equipment is a complex job. The first step toward the solution of a new problem is the analysis of all the requirements that can be anticipated. If they indicate one or more of the properties shown, chances are that Crucible *stainless* steel is the most practical choice you can make.

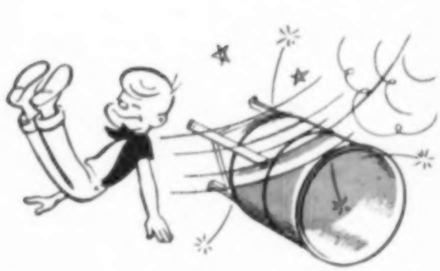
RESISTS CORROSION – Stainless is almost impervious to attack by oxidizing acids like nitric acid. It resists strong alkaline solutions, and many other chemical compounds.

PREVENTS CONTAMINATION – With stainless there's no pickup of metallic ions or deterioration in the product. Stainless stays out of the process solution.

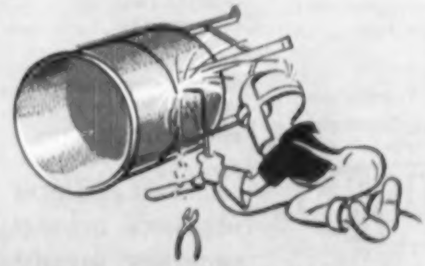
CLEANS EASILY – Even for the most rigorous cleaning problem – that of decontamination to remove radioactive matter – stainless is chosen decisively over other materials.

WITHSTANDS TEMPERATURE EXTREMES – At very high temperatures, stainless stays strong. At very low ones, it does not become brittle as other metals may.

PROVIDES GREAT STRUCTURAL STRENGTH – Stainless is about 50% stronger than mild steel. It permits lightweight, durable construction of chemical processing equipment.



RESISTS WEAR AND ABRASION – Erosive and abrading action makes the surface of stainless harder. It's ideal for mixers, chutes, bins and piping.



ALLOWS COMPLEX FABRICATION – Stainless can be cut, bent, drawn, welded, machined, forged, spun, riveted, cast – fabricated by all the common metal-working processes. Stainless imposes no restrictions on equipment design.

Crucible metallurgists have had considerable experience with stainless in chemical applications. They will be happy to work with you to make the best, most economical use of stainless in your plant. *Crucible Steel Company of America, The Oliver Building, Mellon Square, Pittsburgh 22, Pa.*

Send for a copy of the 44-page booklet "Making the Most of Stainless Steels in the Chemical Process Industries". It's packed with data you can use.

CRUCIBLE first name in special purpose steels

Crucible Steel Company of America

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Noted and quoted

(Continued from page 8)

silica type. For nearly fifty years research has been carried on with dispersions of lithium, sodium, potassium, rubidium, and cesium with isoprene. More recently lithium wire has been used which produced the synthetic natural rubber. A United States patent on this process was issued over forty years ago and only today its potentialities are being realized by means of the development of infrared techniques for studying structure.

Such new raw materials as bisphenol-A, phosgene, dichlorocyclaoxabutane and the fluorinated unsaturates are being studied and researched now to produce more plastics.

In the inorganic polymer field, where the greatest development may take place, we have only scratched the surface in developing the silanes. Rigid polymers, all inorganic, will be developed and pressed into panels for building and construction purposes, automotive bodies, pipe, and a myriad of articles now fabricated from the organic polymers with the added advantage that they will be fireproof. The catalysts needed to tailor make these polymers are now in the laboratories.

The metal hydrides are being intensively studied for use as raw materials or as intermediates. The hydrides of lithium and aluminum have been suggested for combination with carbon monoxide to produce the primary alcohols. Methanol has already been made on a semi-commercial scale in this manner.

Lignite is being studied as a raw material for many chemicals. Synthetic lube oils and greases are being manufactured out of everything but petroleum. G-E has announced future research in the use of molten metals and molten glass as supersonic lubricants for the "Space Age".

New Tools

A hard look is again being taken at luminous arc processes and silent discharge processes. Several companies have been studying the feasibility of gas phase chemical reactions in luminous high frequency electrical discharges, when synthesis requires high activation energies at relatively low reaction temperatures. A patent has already issued and applications are now pending for further improvements in technique. The most promising synthesis studied is the production of anhydrous hydrazine from ammonia. The technique involved is feasible for the production of high energy rocket fuels

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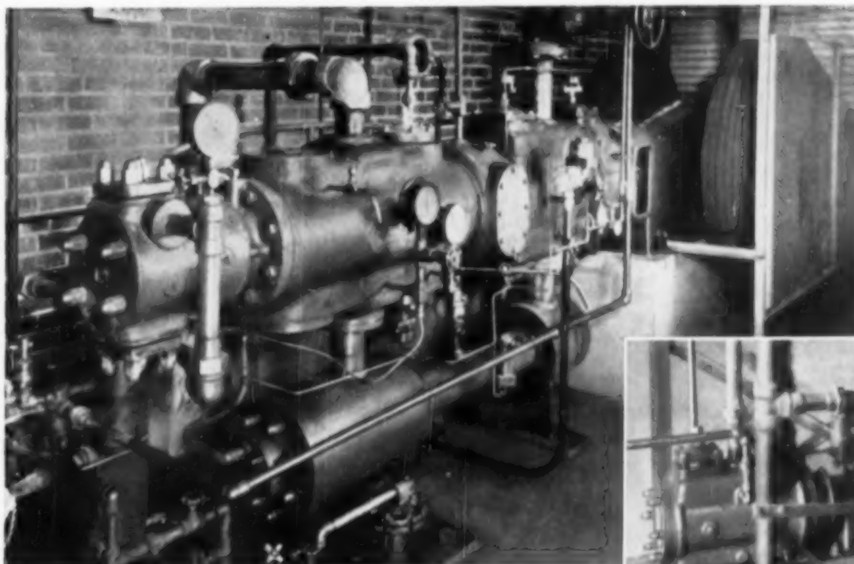

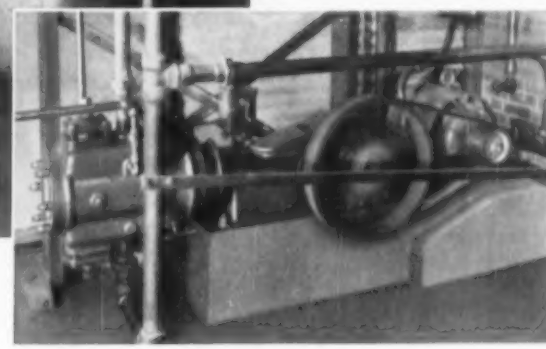

Hydrogen

The 3-stage ES at left compresses hydrogen to 1000 psi, for processing low-grade scrap into pure copper powder.

Natural Gas

This Ingersoll-Rand ER compressor is used as a natural gas booster in the reforming process which produces hydrogen for copper reclamation.

PURE POWDERED COPPER from LOW-GRADE SCRAP

IR compressors play leading role in new recovery method at Whitaker Metals Corporation

Junked motors, copper-clad iron scrap, auto radiators, sweepings and furnace ashes containing brass and copper turnings . . . low-grade scrap which never before could be economically reclaimed . . . all now yield pure powdered copper which is ideal for roll-bonding into rod, strip and tubing stock.

This is possible due to a technique developed by Chemetals Corporation (New York) and first put into operation at the North Kansas City plant of Whitaker Metals Corporation. The key to the process is hydrogen gas, compressed to 1000-psi pressure by an Ingersoll-Rand ES compressor. Whitaker manufactures its own hydrogen from natural gas, using a smaller I-R compressor as a gas booster unit.

These compressors have been operating for more than two years with only routine maintenance attention, and are another example of the dependability of Ingersoll-Rand equipment. This ability to stand up in continuous heavy-duty service means real long-range economy on any type of job. Ask your I-R representative for information on air or gas compressors suited to your specific needs.

ONLY I-R COMPRESSORS HAVE CHANNEL VALVES

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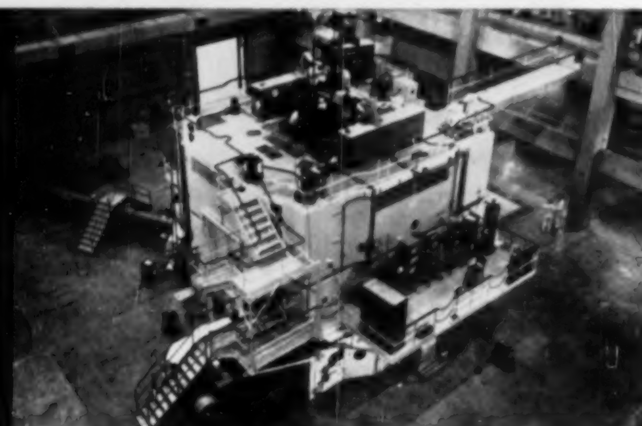
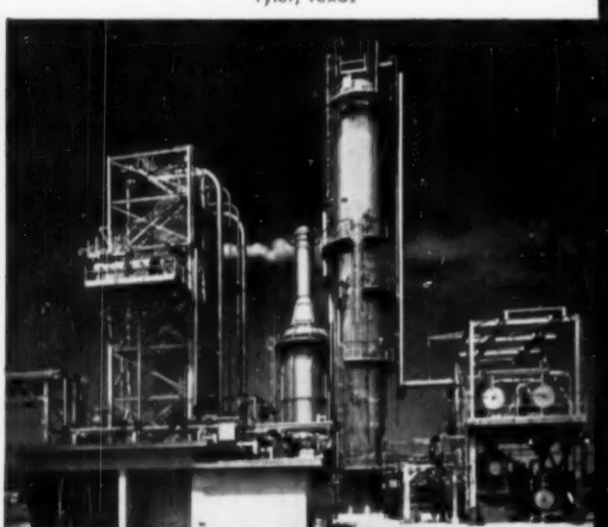
Our engineers will welcome the opportunity to focus this specialized experience on your proposed projects or plant expansions.

Chlor-alkali plant for Olin Mathieson Chemical Corporation
McIntosh, Alabama



Materials testing reactor for the Atomic Energy Commission
Idaho Falls, Idaho

Petroleum refining unit for the McMurrey Refining Company
Tyler, Texas



Resin plant for Glenn L. Martin Co.
Painesville, Ohio

Noted and quoted

(Continued from page 12)

and the synthesis of intermediates for high temperature resistant polymers.

The direct production of steel from iron ore has created a stir in England with the announcement of the work done by the British Iron and Steel Association on a process using the fluidized solids technique. The difficulties with the process lie in the high temperature necessary, the danger of explosion and the inability of present refractories to stand up for more than a few weeks. In our country W. K. Lewis has developed a process using the fluidized bed technique for the direct reduction of iron ore to Fe and FeO with methane at temperatures from 1550-1650° F. Steel companies are contemplating similar processes using hydrogen from one source or another at temperatures ranging from 900-1,700° F. and pressures from 15-400 pounds per square inch.

Boranes and substituted boranes offer interesting possibilities as intermediates for new chemicals. Boron halides open the way to cheaper metal hydrides as well as serving as tools for refining zinc, copper, magnesium, and aluminum alloys. They also have been suggested as polymerization catalysts, as catalysts in inorganic reactions and as Friedel-Crafts condensing agents in organic synthesis. The chloride is effective in the control of magnesium metal fires and has been patented as a stabilizer for sulfur trioxide, an up and coming sulfonating agent and solvent.

Theoretical developments are leading the way to a better understanding of the mechanism of solution and solvent action. A recent announcement that acetonitrile has been substituted for acetone in the separation of the C_4 fraction in a butadiene plant, thereby greatly increasing its capacity, is the opening gun for new uses of another tool. The relative volatilities in this new solvent change from 1.2-1.25 to 2.5. Many possible extractive and azeotropic solvents have never been tried because the basis for selecting the proper chemical has always been haphazard, confused and not well understood. Linus Pauling gave us one of the keys to this new technique in his classical work on the "Nature of the Chemical Bond." Research following up his exposition has shown that previously inconceivable reactions may now be carried out due to a revision of our ideas of reactivity, group interaction, and the influence of neighboring groups upon the distortion of bonds.

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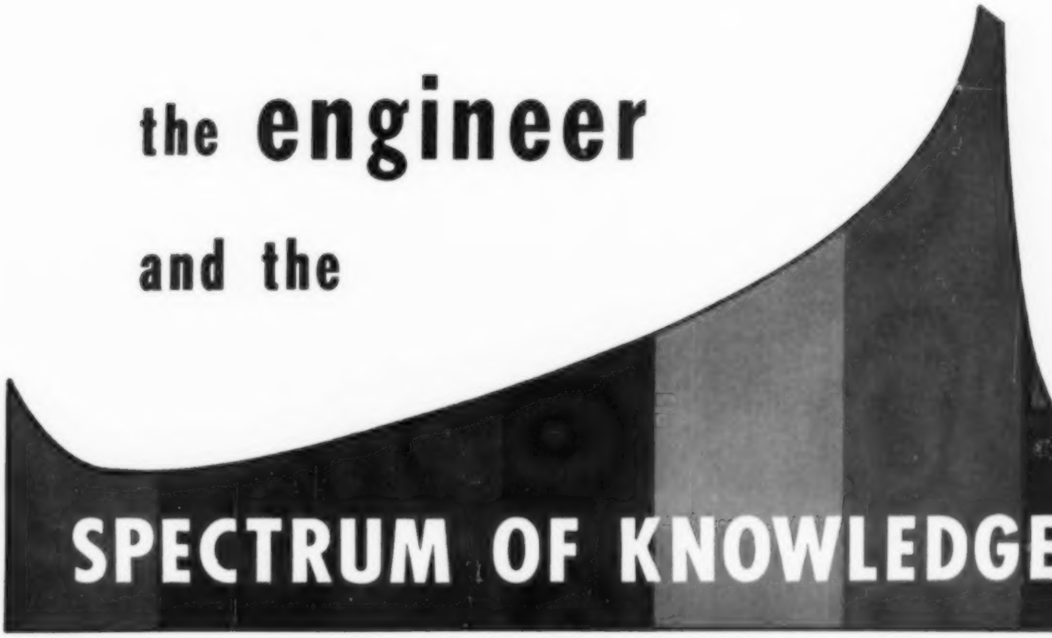
the engineer and the SPECTRUM OF KNOWLEDGE



Robert R. White | University of Michigan, Ann Arbor, Michigan

Fig. 1. Knowledge is ordered and continuous . . .

Today, more than ever before, although one can describe what engineers do, one must not ever say what engineers can not or do not do. In every human activity, technical or otherwise, somewhere there is an engineer.

The breadth and pace of engineering activity defies specific description, and forces a reexamination of the basis of engineering and in fact of all human knowledge if one is to maintain a perspective of the place of engineering and understand the function of the engineer in present-day society. It behooves engineers, especially today, to ask once again the question which is so important that it has become trite with its repetition through the centuries—what is an educated man?—and to recognize that education ends when the undertaker arrives.

It is interesting that a man's education is seldom described in terms of his knowledge of, or ability to do, specific things, such as quoting Shakespeare. While many educated people can quote Shakespeare, all those who quote Shakespeare are not necessarily educated. Education seems to be a matter of perspective, an appreciation of broad values. In the language of physical science, education is the understanding of the evidential, deductive, and inductive bases of a broad area of knowledge, which in the last analysis constitutes *judgment* or *wisdom*. An educated man, for example, be he scientist or not, appreciates the meaning of the factual statement "This table is three and one-half feet long"; he understands that it is not two or four feet long but may be three feet four inches or three feet nine inches long. If the statement is "This table is 3.516 feet long," he understands that a precision of probably ±0.001 foot is involved and wonders why. The educated man understands the absurdity of the statement "The table is approximately 3.5163478 feet long"! However, an educated man also understands the statement of fact "Michelangelo was a great artist" and recognizes the difference between the evidence and precision of the evaluation behind this statement and those behind the statements about the length of the table. To put it simply, education is in part synonymous with an appreciation of the uncertainties involved in describing various facts and the difficulties in relating facts of different kinds.

It is possible to classify, in a rough sort of way, all human knowledge according to the uncertainties involved in its description. The notion of the order of knowledge is discernible in

the writings of the ancient Egyptians and Persians. It was amplified through the ages by such philosophers as Aristotle, Sir Francis Bacon, and Auguste Comte. The notion that knowledge is ordered and continuous is illustrated in Figure 1.

The most precise area of knowledge is probably that portion of mathematics which is devoted to finding the logical consequences of sets of arbitrary postulates. It is represented by the minimum point on the curve relating uncertainties to the position in the spectrum of knowledge. Mathematics is unusual in that the selection of its postulates shades rapidly into the area of philosophy, and so its range of uncertainty covers probably not only the minimum, but also the maximum, observable in human knowledge. It is significant that many outstanding philosophers, such as A. N. Whitehead and Bertrand Russell, have also been expert in mathematics.

After mathematics, other branches of knowledge might follow in some order, such as the physical sciences, including physics, chemistry, astronomy; the natural sciences, including such areas as biology, zoology; the social sciences, including economics, political science, psychology; the humanities, including linguistics, language, and literature; and the fine arts through religion and ethics, which also shade into philosophy.

In order to relate the engineer to the spectrum of knowledge, we must examine for a moment some of the characteristics of engineering. One can compare the present growth of engineering with the constantly accelerating progress of a bulldozer clearing a path through a dense woods. In front of the bulldozer are the rubble and trees which might represent the lack of knowledge in our future path, whatever it may be. Behind the bulldozer is a relatively smooth, clear path representing the knowledge which we have attained. And at the blade of the bulldozer there is a zone of turbulence representing our active areas of research and creative development.

Although we need engineers who will work in relatively familiar areas, the universal cry is for engineers who can work in the zone of turbulence, on the frontiers of chemical and industrial developments.

The bulldozer seems to be not only moving faster and faster but also plowing up a greater and greater front, and our real need is to train people who can survive the present zone of turbulence, and also help to make and then live in the one which is to come in the future. A man educated to survive in the turbulence of creative engineering will have little difficulty in acquiring on the job or elsewhere the training needed to carry out engineering assignments in the well-plowed and established areas.

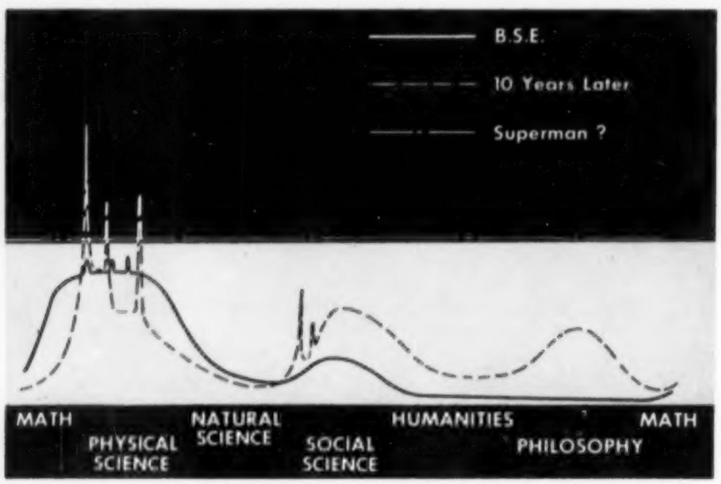


Fig. 2. Plot of quantity of knowledge in relation to the spectrum of human knowledge.

The characteristics of engineering problems which separate the men from the boys seem to be as shown in Table 1.*

Table 1.—Characteristics of Engineering Problems That Separate Men From Boys

1. Number of variables is unknown
2. Number of variables > number of relationships
3. Relationships are usually inequalities
4. Payout function is to be evaluated
5. Payout function includes time and cost of engineering

The total number of variables in a typical engineering problem are rarely known, and all engineers probably have had the experience of developing a fine solution to a problem only to discover, sometimes too late, a new factor that invalidated or seriously altered the applicability of the solution.

Furthermore, because it is also true that the number of factors known to be variables almost always exceeds the number of relationships between the variables, there are, in general, an infinite number of solutions to engineering problems and many satisfactory ones.

The third statement in Table 1 is seldom emphasized enough; yet it represents an important characteristic of engineering, namely that engineers are concerned more with *inequalities* than with equalities. When we design a beam, we base our design on the yield strength of the material, but we make certain that we do not exceed it. We design fractionating columns with more than the minimum number of plates to operate at more than the minimum reflux ratio. In solving our problems we work basically with incomplete systems of simultaneous inequalities and a few equalities. In fact, sometimes we are hard put to it to express some of the relationships between variables in the form of either an equality or inequality.

The fourth statement reflects the basic ground rule of engineering. Directly or indirectly, we must always focus our effort on the price we have to pay for a given result or set of results.

Finally, there is the characteristic which especially irritates the pure scientist. The cost and time of solving the problem are part of the engineering problem, part of the payout function. This is why we often build plants and produce and sell products long before we have completed the engineering which might be done.

It is these characteristics which distinguish engineering from science and mathematics, and it is in the uncertainty and incompleteness of our problems and of the knowledge available to solve them that we find our greatest opportunities as engineers. These uncertainties, which in effect characterize engineering, obviously require engineers who can cope not only with the relatively definite

* Tribus, M., remarks at a meeting of *ad hoc* committees, A.S.E.E., Ann Arbor, Michigan (Dec. 1, 2, 1956).

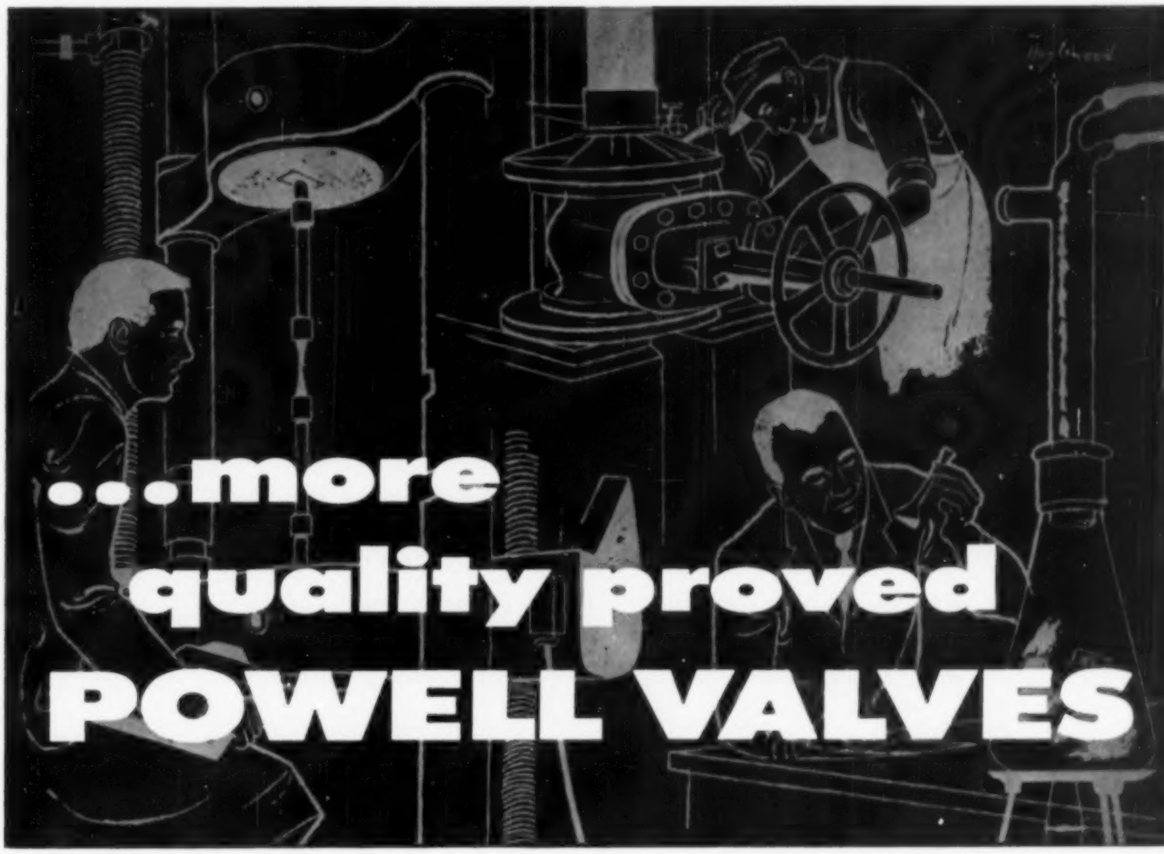
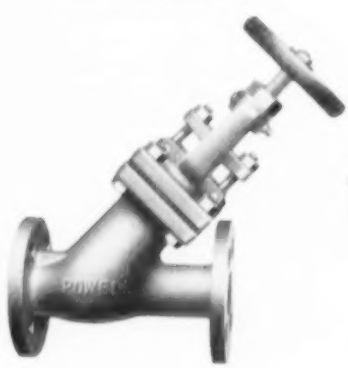


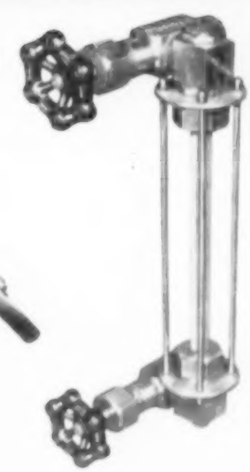
FIG. 2309 – Flush Bottom Tank Valve for 150 Pounds W.P.

FIG. 2491 – Stainless Steel O.S.& Y. Gate Valve for 150 Pounds W.P.

FIG. 1886 – Stainless Steel Liquid Level Gauge for 350 Pounds W.W.P. Offset pattern.

FIG. 2107 – Stainless Steel "Y" Valve for 150 Pounds W.P.





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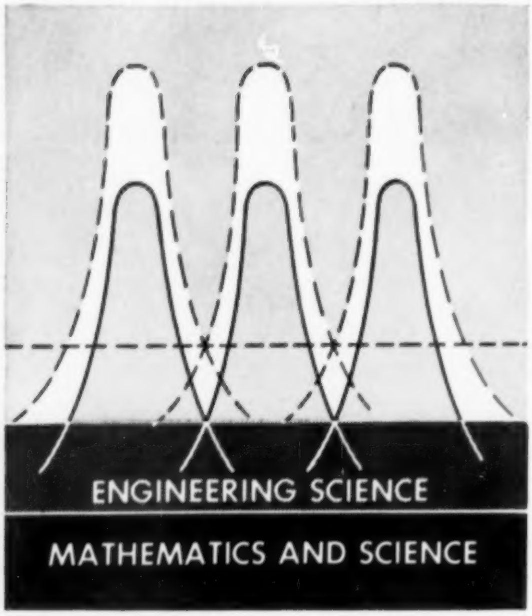


Fig. 3. Engineering curriculum.

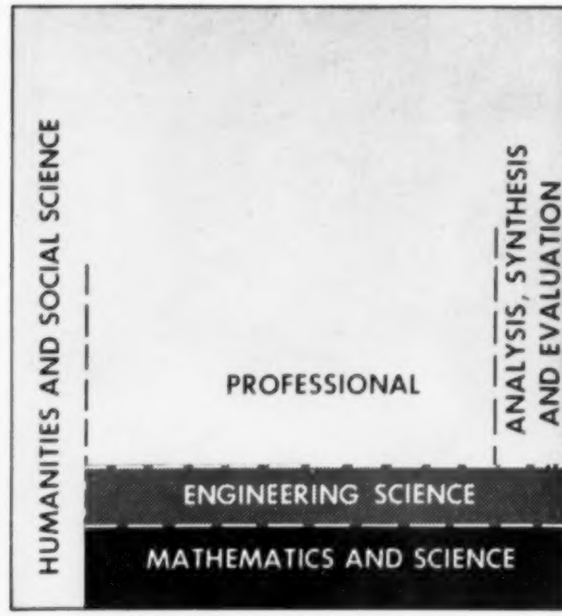


Fig. 4. Development of Engineering Science.

aspects in the realm of physical science and mathematics, but also with the indefinite aspects involving such factors as economics, human behavior, etc.

Let's look at the characteristics of an engineering problem more carefully. They are the characteristics of problems (or decisions) that any kind of executive has to face repeatedly. His ability to handle the uncertain as well as the certain areas of knowledge involved measure an executive's effectiveness. They are the characteristics of the problems of a medical doctor, of a dentist, of a lawyer, of any man in management: they are the problems of any professional man. It should be safe to generalize by saying that the characteristics of an engineering problem are one way of stating what is expected of an educated man who effectively applies his education in society. In short, the engineer should be educated. He must appreciate the values and the uncertainties in a wide range of the spectrum of human knowledge.

Figure 2 shows what might be a typical plot of the quantity of knowledge in relation to the spectrum of human knowledge (that is, a distribution curve), for a typical graduating senior in engineering (solid curve). He knows a fair amount of mathematics and a relatively large amount about physical science. He has developed a few small bumps of specialization in the physical science area through his professional courses. He has not much natural science, he has a small amount of social science in the form of economics, and usually he has a very small amount of the humanities and philosophy. What might happen to his distribution curve after ten years? This is represented by the dotted curve, showing that because of his work he has developed some of the small bumps to tremendous peaks of specialization, involving great manipulative skill and a detailed cataloguing of fact in a relatively small area. He has probably forgotten more mathematics than he has learned, but he has also probably developed some special knowledge of economics represented by the bumps in the social science area, and certainly, through the experience of simply living longer with people, he has a better grasp of social science and humanities. "Superman" is represented as knowing a great deal about everything. Such a man ought to be a creative genius.

Education seeks to give to an average young man knowledge that will help him to develop peaks of specialization when and where he needs them and experience and perspective that will enable him to cope with the distribution of values indicated in Table 1. A precise description of this distribution being impossible, a few of the more evident factors are presented here.

The rapid pace at which technology is changing makes specialization in school, with the object of using that specialization in an engineering career, quite foolish, for the peaks required today may not be needed tomorrow and what does remain tomorrow will be easily acquired. We do know that specialization can be built very rapidly on well-distributed knowledge. This and the ever-increasing breadth of engineering problems argue strenuously in favor of a "superman" distribution. It is perhaps the area under the curve that is important rather than any single peak or group of peaks. There probably should be some specialization at the undergraduate level for the sake of illustrating what specialization is, but there seems to be little other argument for it.

Table 2

1. Mathematics, physics, and chemistry
2. Engineering science
3. Engineering analysis and design
4. Professional work
5. Humanities and social sciences

"Engineering Science"

The so-called "engineering science" or "science engineering" curriculums which are beginning to appear at a number of universities represent an attempt to redistribute the emphasis in engineering education more broadly over the spectrum of knowledge. In general these proposed curriculums conceive of engineering education in the areas listed in Table 2. The interrelation among the areas of Table 2 is indicated in Figure 3.* The dotted

* Brown, G. S. at a meeting of *ad hoc* committees, A.S.E.E., Ann Arbor, Mich. (Dec. 1,2, 1956).

boundaries between areas indicate interaction.

Education in mathematics, physics, and chemistry is reasonably familiar, but the concept of engineering science is newer and deserves some attention. As we all know, there are many aspects of classical physics and chemistry that these sciences have long since abandoned as being uninteresting fields of investigation—for example, liquid-vapor phase equilibria. The development of distillation operations, however, required large additions to the knowledge of these fields, and, because there was no one else to do the work, for the most part chemical engineers filled the gap. A similar acquisition of scientific information with its correlation and extrapolation (which is of course science itself) has occurred, and is now occurring, in all branches of engineering. The knowledge created by an area of engineering soon overlaps knowledge created in another branch of engineering, such as the knowledge of fluid mechanics developed by civil, mechanical, chemical, and aeronautical engineers. The process of overlapping is shown in Figure 4,* in which the peaked curves represent the different areas of engineering.

When this scientific knowledge spreads to reasonably broad areas of engineering, it may be called *engineering science* and superimposed upon mathematics, physics, and chemistry. It is the hard core of scientific knowledge, mostly created by and useful to engineers, which all engineers need to understand. Figure 4 also illustrates how, when a relatively specialized area develops a higher peak, the overlap at the base tends to increase, thereby increasing the extent of engineering science, a process which may be expected to continue rapidly in the future.

The history of what may be called the *transfer and rate process* illustrates how chemical engineering has been responsible not only for much of the broadening of concepts of engineering, but also for the creation of engineering science in the area of transfer and rate processes.

The integration of engineering science with mathematics, science, and engineering subjects into an engineering curriculum is illustrated by the Science Engineering curriculum at the University of Michigan, which is summarized in Figure 5.

The Agonizing Reappraisals

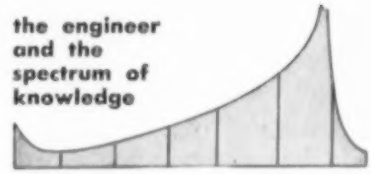
The movement of engineering—and especially chemical engineering—leading to the engineering sciences, has not only forced an agonizing reappraisal of what is fundamental in engineering knowledge, but is also having considerable impact on other fields such as mathematics and the humanities and social sciences—all in the direction of broadening the interplay of these disciplines with engineering.

This might be expected to be most apparent in the field of mathematics, the language in which engineering problems are restated in quantitative fashion. This restatement almost always involves the concept of a mathematical model the operation of which is predicted by mathematical manipulation. When the operation of the model is compared with the physical situation that it is supposed to approximate and a reasonable correspondence is achieved between the two, we say that we have correlated the data, or we have solved the engineering problem. As we apply models to broader and broader engineering problems as we are now doing, particularly in the fields of operations research and systems analysis, we correspondingly extend the spectrum of mathematics that we find useful to us. Figure 6 * shows the two-by-two matrix of mathematical models described as being either analytic or numerical, deterministic or stochastic. The engineer and the scientist both have occasion to use all the types represented here.

For example, $F = ma$ as shown in the analytic-deterministic example is analytic because it is a specific equation and deterministic in that if values are assigned to any of the two symbols, the third is completely determined, no deviation from this relationship being permitted.

The analytic-stochastic example is illustrated by the Poisson distribution expressing the statistical statement that on the average a certain number of events will occur in a given interval of time. It is analytic because it is in equation form and stochastic be-

the engineer and the spectrum of knowledge



* Grinter, L. E., Remarks at a meeting of ad hoc Committees, A.S.E.E., Ann Arbor, Mich., (Dec. 1, 2, 1956).

* Goode, H. H., paper presented at meeting of Operations Research Society of America, San Francisco (Nov. 16, 1956).

Fig. 5. Univ. of Michigan science engineering curriculum.

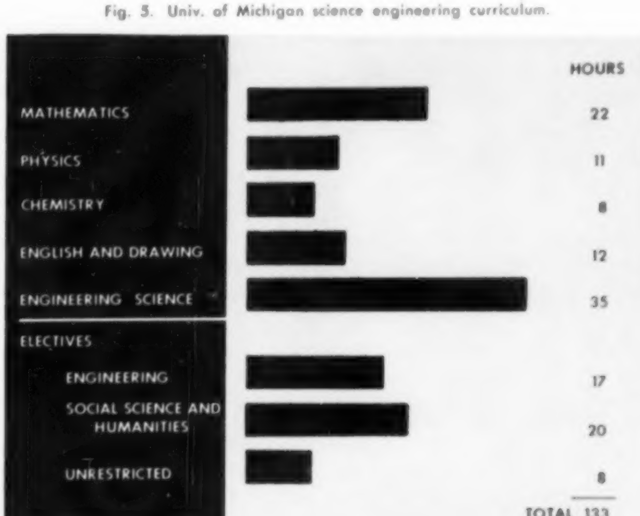


Fig. 6. Types of mathematical models.

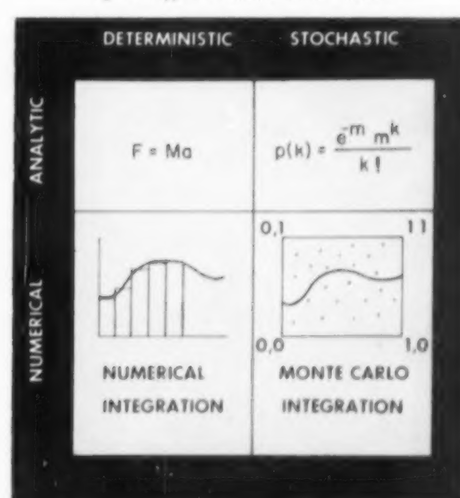


Table 3

	%
Analytic-deterministic	80-95
Numerical-deterministic	15- 4
Analytic-stochastic	5- 1
Numerical-stochastic	Trace

Table 4

	%
Analytic-deterministic	30
Numerical-deterministic	40
Analytic-stochastic	20
Numerical-stochastic	10

cause it says nothing about any particular occurrence.

A numerical-deterministic model is illustrated by a numerical integration with which all chemical engineers are thoroughly familiar. It is numerical because it is evaluated basically by a set of numbers such as a table of data, and it is deterministic because it represents a one-to-one relationship between the function and its integral.

A numerical-stochastic operation is illustrated by the Monte Carlo integration in the lower right-hand corner. Here, in order to integrate a function, a scale is selected so that the entire portion of interest lies inside a unit square. A large number of points are plotted from a table of random numbers lying in the interval from 0 to 1 and then the number of points falling between the graph of the function and the x axis are counted. The ratio of this number to 1 represents an estimate of what fraction of unity the integral is. Of course, this result could have been obtained much more quickly with a planimeter; however, in the case of five or six variables, the method may have some utility. It is used here only for illustrative purposes.

The use of stochastic and numerical models has been seriously hampered in the past by the large number of calculations involved, which the availability of automatic computers will make negligible and thereby bring numerical techniques into effective competition with analytics. The important point is that these computers make possible our undertaking the quantitative analysis of problems which heretofore could not, or would not, be considered. Such applications will multiply rapidly.

At the present time the average engineer's mathematical training and experience might be distributed as in Table 3. It is small wonder that his primary approach to engineering problems tends to be deterministic in philosophy and his first attempts at solution tend to be analytic, or, these failing, numerical with much apology.

Chemical engineers live with stochastic processes, namely turbulence in fluids and, even more directly, in mixing and contacting. So far little has been done in these areas except from a deterministic viewpoint. Future engineers, particularly chemical engineers, should not only have more mathematics, but perhaps a different kind, distributed as in Table 4.

Other groups, not yet professions, are already doing this. History shows clearly that when a new group of people can solve problems more effectively than an old, a new segment of professional society arises. Mechanical engineering was the new group which separated from civil engineering, chemical engineering from mechanical engineering and chemistry, nuclear engineering may separate from chemical; operations research groups now distinguish themselves from the other groups of engineers.

An unwillingness or inability to adopt and adapt these new ideas and techniques is equivalent to a hardening of the arteries, and complacent attitudes which regard the unit operations and reaction kinetics as typifying chemical engineering for all future time bodes ill for the profession. If such a trend continues, we shall ultimately have a clearly definable and well-bounded profession—one without intellectual freedom or future.

We chemical engineers are in an engineering pattern that is basically turbulent:

> **Big-size whirls have little whirls**
> **That feed on their velocity;**
> **Little whirls have lesser whirls**
> **And so on to viscosity.**

I wonder sometimes whether chemical engineering, which is at present a big whirl in the turbulent field of engineering, is not investing its velocity in too many little whirls, lesser whirls, and viscosity instead of trying to make the big whirl grow bigger and go faster. We tend to forget that we are in a large moving stream and prefer to contemplate the little whirls as Buddha did his navel. Little whirls are fun to chase; at one time the Institute was publishing so many papers on packed towers that it was referred to as the American Institute of Packed Towers. Certainly in the opportunities available to chemical engineers at that time, packed towers were a mighty small whirl.

In addition, some of the most revered calculations of chemical engineering may be becoming small whirls. It seems reasonable to suppose that it will not be long before pressure-drop and heat-exchanger calculations will be tabulated and on file. Or take the glamor boy of chemical engineering, multicomponent distillation. Plate-to-plate calculations are already so mechanized by the digital computer that they will soon be a dead issue, if they are not already.

The increasing scope of engineering is also having a strong impact on humanities and social sciences. It may surprise engineers to learn that educators in these areas have the same difficulty with specialization that they do. One professor in the humanities remarked, "The only broadly educated people in the university are the graduating seniors." As engineering undertakes more and more the quantitative and semiquantitative treatment of problems involving human behavior, interactions among engineering, the social sciences, and the humanities will grow. There are now systems problems which involve not only engineers, physicists, and chemists, but also mathematicians, psychologists, and even archeologists. In fact, the impact of engineering, which in a sense reflects the over-all impact of our technical culture, may do more to demonstrate the everyday utility of knowledge in the relatively uncertain areas of the humanities and social sciences than any other single factor.

In developing professional men, which areas of the spectrum of knowledge should the universities present and which should industry undertake to teach?

There is little doubt that a primary function of the university should be to establish a broad, relatively high, level of distribution of knowledge over mathematics and physical science. The universities can also provide experience in the uncertainties and values to be found throughout the rest of the spectrum of knowledge by providing the student with an intensive study of a relatively few examples well distributed over the spectrum.

On the other hand, industry is far better motivated and equipped to train along specialized lines and therefore has as one of its primary functions the responsibility for developing the desired "peaks" suitable for business.

Universities seem competent to do a good job on the theoretical side of economics and could establish a rather broad "bump" in the social-science area which would support the specific peaks representing a company's particular problems in marketing, sales, and market development. Industry is in a fine position to give basic training over the areas of the social sciences and perhaps even the humanities. It has an operating system composed of

the engineer and the spectrum of knowledge

many different kinds of people, covering many interests. Nowhere are the questions of group dynamics and motivations more clearly illustrated than in the operation of a company. In such a natural laboratory, industry should be able to develop many of the concepts of the social sciences at least as effectively as can the universities.

A number of provocative questions arise when one considers the function of graduate work.

In terms of the requirements of engineering problems, as has been pointed out, the only excuse for specialization is to provide the student with a knowledge of what specialization is. At the present time the whole concept of graduate work in engineering is that of specialization. Faculties wait with bated breath for the student to select his field of interest, that is, the topic on which he elects to do Ph.D. research if his academic qualifications meet certain arbitrary standards established over the years.

The epitome of graduate work is the Ph.D. degree, which often consists of two or three years of research on an extremely specialized topic superimposed upon a year or two of graduate course work. Universities are rather proud of the fact that "they make the student do his research himself." In other words, while he receives comments and counsel from his research supervisor, the student has to learn the necessary experimental techniques by trial and error; he spends a great deal of time as a plumber, electrician, carpenter, machinist, glass blower, etc.

In fact, one might estimate that Ph.D. research often consists of about 70 per cent of the student's time spent in trades recognized by the American Federation of Labor, about 10 to 15 per cent in operation of the experimental equipment to obtain data, perhaps 5 or 10 per cent in creative thought about the meaning of the data, and the remainder of the time in the writing of his book called *The Ph.D. Dissertation.* He is then handed his union card for teaching, the Ph.D. degree; he has the label of expert, although perhaps only a half dozen people will understand exactly in what way he is expert, and he then marches out into the world as representative of the highest accomplishment of engineering education.

Even a cursory matching of the acquisitions of a Ph.D. candidate during his graduate career against the spectrum of knowledge needed in engineering indicates that his specialization and very small added distribution have been obtained at a fearful price in time and effort.

It appears that industry is interested in Ph.D.'s not because of any specialized knowledge they may have obtained by virtue of their research, but primarily because a Ph.D. is usually a pretty good man, as he has had to pass qualifying examinations and a considerable number of admission and course requirements, and he certainly demonstrated the virtues of dogged persistence and ambition.

It is ironic that the present meaning should adhere to a Ph.D. degree, which was originally formulated on the concept of great breadth through creative thought rather than on the notion of specialization. After all, Ph.D. are initials for Doctor of *Philosophy.* As our culture has become more complicated, the acquisition of great breadth and insight has become more difficult. We have seized upon the "creative" notion and have warped its interpretation to cover the acquisition of factual information even though such work involves no creative thought whatsoever. It is significant that in the fine arts such as music, one must do much more than compose a piece of music. Even a creative masterpiece does not satisfy the original philosophic basic of the Ph.D. requirements.

If we really look at the characteristics which distinguish engineering problems, we can make a frontal effort to develop the necessary wisdom.

The objectives of graduate work in engineering should be reconsidered. Its primary function should be the attainment of a thorough experience in the solution of complex engineering problems distributed over a wide area. Comprehensive plant designs, including economics and operations; market evaluation and study; technical surveys of broad areas of engineering knowledge; planning of research and development programs—all these provide fine opportunities to produce engineers who know how and where to develop in a short time specialized peaks of knowledge required for the solution of specific problems but whose principal characteristic is a broad distribution curve, perhaps, one can hope, approximating that of "Superman."

Graduate work should include more and broader mathematics, well into its philosophical aspects, and a rather thorough treatment of the social-science area, emphasizing particularly economics, psychology, sociology, and geography, virtually omitting two- and three-year expeditions into restricted research. Such programs of education would be much more difficult to teach and would require the active cooperation of industrial people, particularly in creating, teaching, and evaluating standards and performance in the comprehensive problem area. The solutions to such problems could well be presented both orally and in writing to retain the values gained in preparing and presenting the Ph.D. dissertation.

As a man obtains "height" through specialization in an area of knowledge, he deals more and more with the "uncertain" aspects of the field and the fine grain of its factual structure.

In terms of the plot of uncertainty vs. position in the spectrum (Figure 1), study in the humanities, where one encounters uncertainty early, may be equivalent to advanced work in physical science or engineering, where one encounters uncertainty late, in developing the ability to grapple with uncertainty. In fact, the ability to transfer the intellectual disciplines of one area of the spectrum to another is of crucial importance in creative thought.

The nature of human thought is an obscure and little-understood phenomenon. While we dearly love to think of ourselves as logical and as competent to proceed from a set of postulates down a straight analytical line to our conclusions, the actual process does not work out that way, particularly in any kind of creative effort. The twists, turns, recycles, and false starts in any creative thinking process are numberless. At the conclusion of every research project we look back with a sense of embarrassment at how easily we might have done the job in comparison with what we actually did. Those feed-back characteristics of the creative thinking process are unquestionably enhanced by a widely distributed knowledge.

This discussion has attempted to illustrate the relationship of the spectrum of human knowledge and our concepts of the process of education to the characteristics of engineering and the qualities needed in engineers. To describe the spirit and development of the new ideas in engineering education which are being forced by the rapid advance of engineering raises ideas as controversial and speculative as those about the future form and function of engineering itself. This apparent chaos, created by the progress of engineers, is a measure not only of past accomplishment, but of future opportunity.

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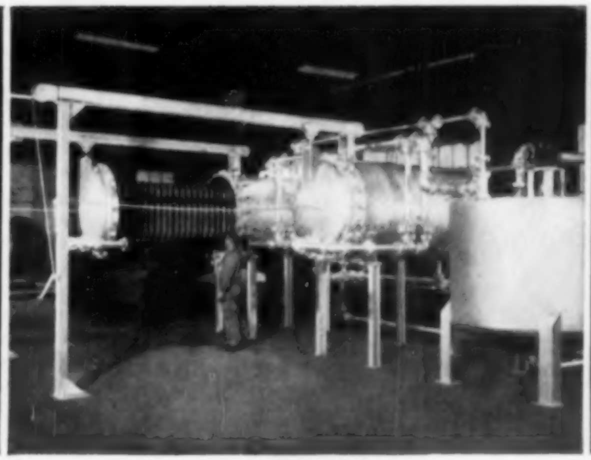

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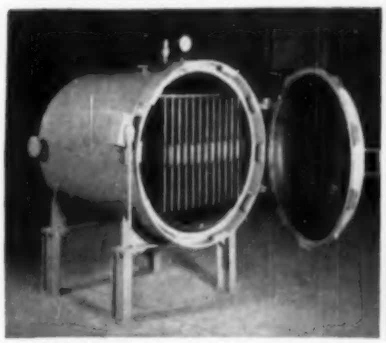

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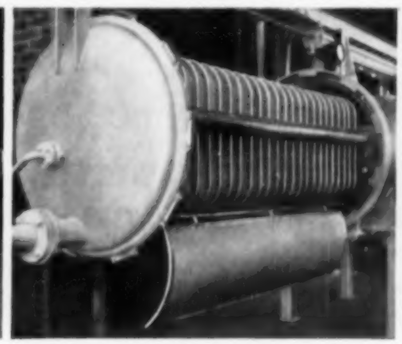

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Noted and quoted

(*Continued from page* 18)

Esso's "hydrogen donor diluent" compounds have the property of being able to transfer hydrogen to other compounds. This transferable hydrogen amounts to 200-600 SCF/bbl. of donor diluent. They have a boiling range of 500-700° F. and can be made from low cost material such as partially hydrogenated thermal tar from catalytic cracking operations. Esso is using them experimentally to recover oil from tar sands. This opens up possibilities for some economical hydrogenations with other suitable donor diluents.

The newly developed uranium solvents, dodecyl phosphoric acid, di-(2 ethyl hexyl) phosphoric acid and some of the secondary amines behave more like "liquid ion exchange resins" than ordinary solvents. A chemical equilibrium, not a physical equilibrium controls the amount of solute held by the solvent. The solute forms a chemical complex with the solvent molecules. Many phases in the field of chemical complexes are being re-examined as tools for future processing.

The metal alkyls such as aluminum isopropylate show increasing possibilities as a tool for synthesis of higher alkoxides, chelates and acylates. They offer direct methods for the production of metal soaps, and are efficient intermediates in alcoholysis and ester exchange.

The use of sonic vibration as a method for causing solids to flow freely has been known to industry for some years. Other uses for this tool are becoming apparent. It has been used experimentally to separate close boiling isomers by distillation and has been suggested as a means of improving heat transfer coefficients in heat exchangers. Now experiments are being carried out using sonic vibrations to produce certain gas phase reactions.

Liquid thermal diffusion may offer commercial possibilities in the field of hard-to-separate materials following the work of S. H. Jury, who has developed an experimental unit that departs radically from the usual vertical thermogravitational columns. The equipment employs a permeable membrane sandwiched between horizontal channels in the hot and cold wall surface. Process economics presently will limit the use of the new equipment to small volume separations, but its development has gone a long way toward clearing up the confusion that obscured the basic principles of thermal diffusion.

Presented at A.I.Ch.E. meeting, White Sulphur Springs, West Virginia.

HOW TO SELECT WATER-CONDITIONING EQUIPMENT (NO. 2 OF A SERIES)

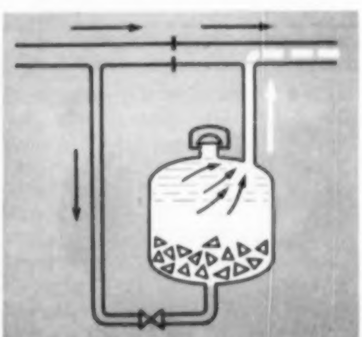
Chemical Feeders

Practically all water-treatment systems include addition of chemicals for one or more purposes: as coagulants to adsorb color, organic matter, oil and turbidity; to raise or lower pH; for lime softening; to inhibit corrosion; to kill bacteria; to adsorb tastes and odors.

The method of feeding the chemicals depends on the kinds used and on the volume, accuracy and proportions required. In general, solution feeders are used for smaller dosages and chemicals which can't be fed dry; dry feeders for large dosages. Here are some of the most-used types of feeders:

Pot type feeders

These are used for slow-dissolving chemicals in crystal or lump form (alums, sal soda, etc.) or special briquets. The chemical is placed in the feeding pot where it is dissolved by by-pass water flowing from the high-pressure side of an orifice to the low-pressure side. Since this flow is proportional to the main flow, the amount of chemical fed is proportional. Variations in amount and solubility of the chemical can, however, affect the feed rate.

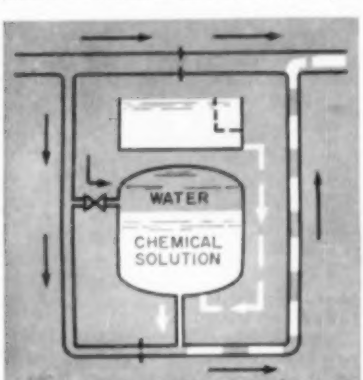


POT TYPE FEEDER

Pressure solution feeders

These allow use of lower cost chemicals (aluminum sulfate, soda ash, etc.) than pot type feeders and provide more accurate control. The chemical is dissolved in the open tank. When needed, the solution is charged into the bottom of the pressure tank, and the displaced water, being lighter, flows out the top to waste. A sight glass float shows the level of the chemical solution in the pressure tank. When on the line, the feeder feeds from the bottom.

Note that solution feed is into a by-pass circuit instead of directly into the raw water line. This eliminates a long vertical run of undiluted solution which, because of its greater weight over the water in the circuit, could affect proportional feeding accuracy.



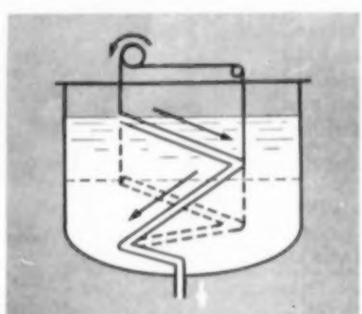
PRESSURE SOLUTION FEEDER

Gravity orifice feeders

A solution of known concentration flows through an adjustable orifice under constant head to provide the desired rate. For intermittent feed, a solenoid valve on the orifice discharge line is operated simultaneously with a raw water pump. Low in cost but limited to constant water flow rates and clear solutions that will not clog the orifice.

Decanting type feeders

This type is known as Permutit Electro-Chemical Feeder. A swing draw-off pipe is lowered at a speed that draws off solution at the desired rate. Feeds practically any type of solution or slurry used for water treatment.



DECANTING TYPE FEEDER

For proportional feeding, a water meter operates a timer that starts the feeder motor which lowers the draw-off pipe for a pre-set period. The timer controlling the lowering rate is easily adjustable allowing wide flexibility and accurate control. Rugged construction. Available with mixing propeller and with cover and dust evacuator.

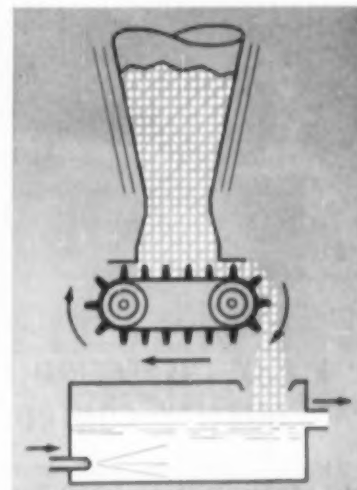
Reciprocating pumps

Pumps with adjustable length of stroke are widely used as feeders . . . generally operated by a meter and timer. Since volumes fed per stroke are uniform, feeding is accurately controlled.

A duplex or double pump feeds one solution to 2 or more points . . . or 2 or more solutions to the same or different points . . . in adjustable proportions.

Dry chemical feeders

A displacement type dry feeder eliminates batch weighing or measuring of dry chemicals and delivers a constant flow of accurately measured amounts of dry chemical (by volume) to a mixing chamber through which water flows at a sufficient rate for good mixing and to prevent settling.



DISPLACEMENT TYPE DRY CHEMICAL FEEDER

The chemical is discharged from a vibrated hopper onto a moving belt with lugs which "slice" off equal, exact volumes of the dry material. The belt speed is adjustable to deliver from 0 to hundreds of lbs. per hour by simple setting of a stepless speed changer. Adjustable while feeder is running, if required.

The feeder can be designed for constant rate feed or, with a meter and timer, for proportional feeding. Feeds practically any type of non-deliquescent dry powder or granules. Can be equipped with counter to show cumulative amount of chemicals fed.

• • • •

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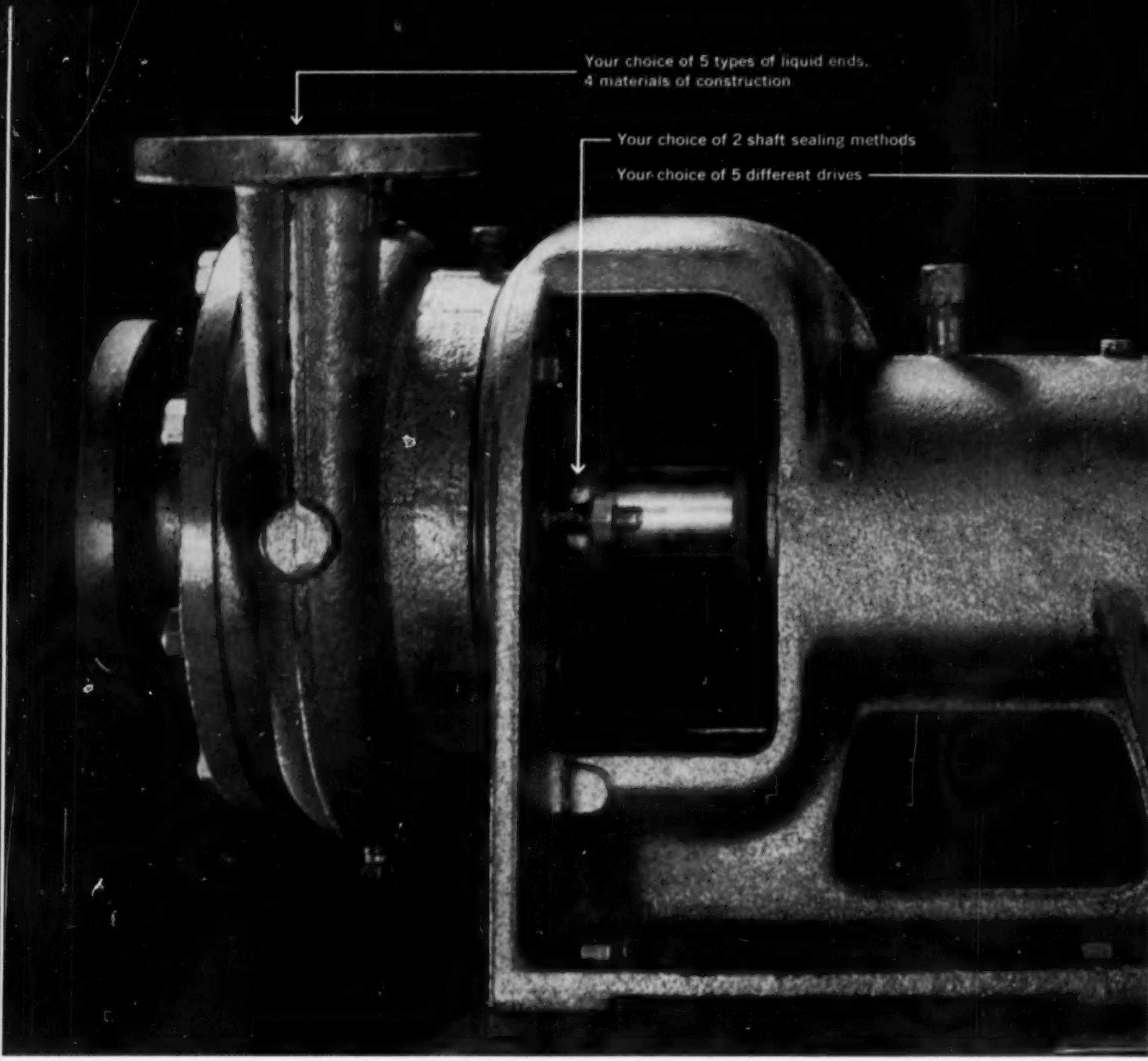

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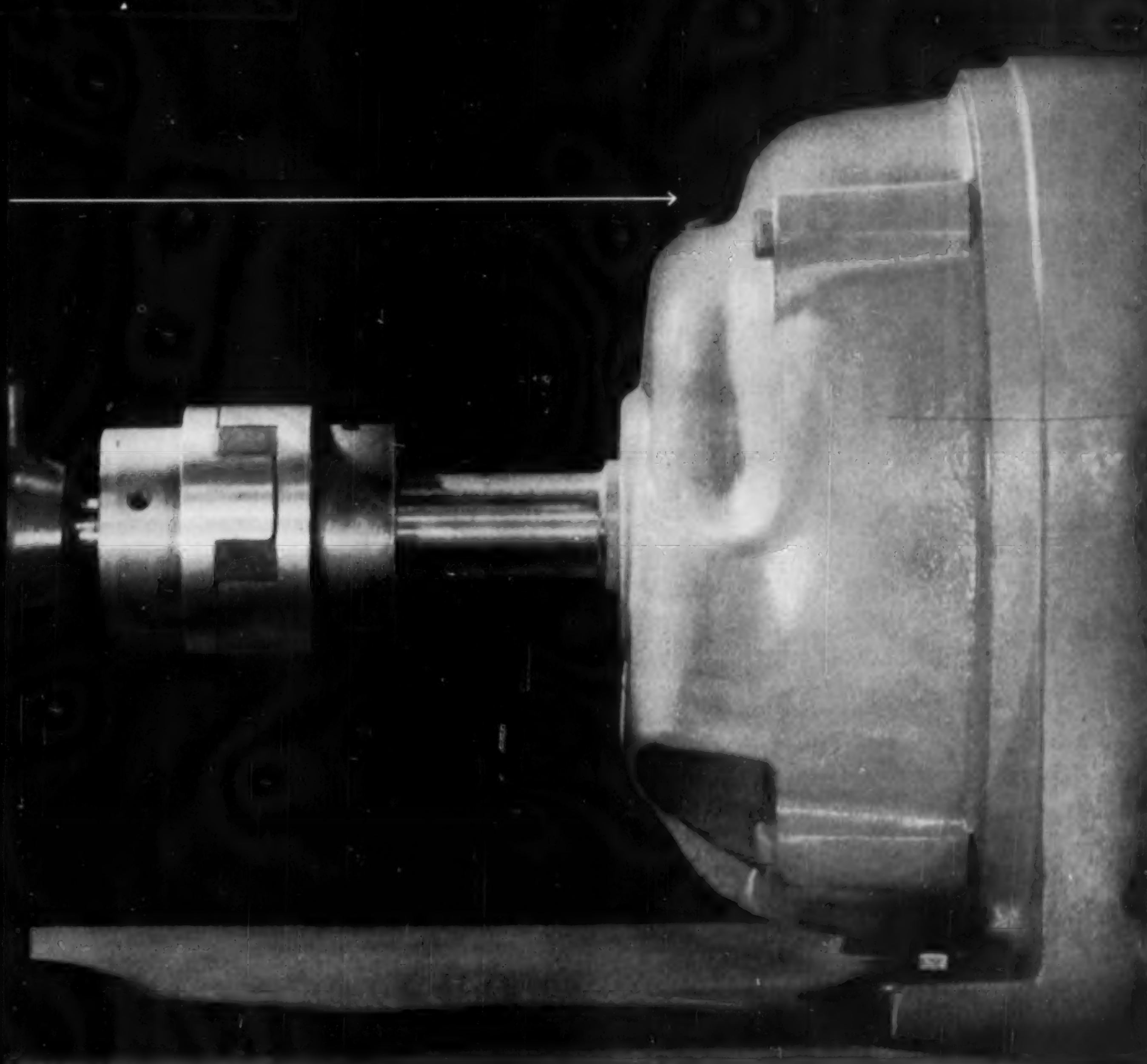


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Letters to the editor

What's Wrong With Coconuts?

I have just finished perusing the March 1957 issue of *Chemical Engineering Progress*. I was struck by the opposite polarity of quality of the articles in that issue on the overlapping questions of unity of the profession, professional recognition, etc.

W. K. Lewis' article . . . is an outstanding contribution to the literature of its subject and, in my opinion, should not be permitted to pass into the limbo of library files.

The article based on Sarah Ruth Watson's A.S.E.E. paper is certainly open to a great deal of question. It is interlarded with the same superficial interpretations of modern history so characteristic of the rank and file of those who enunciate the so-called "liberal line." You will note, for example, her equating the revival of orthodox religion with the rise of anti-intellectualism. I submit that it is indeed this very superficiality, typical of the pseudo-scientific pronouncements coming from so many directions, which drive many to the refuge of so-called "anti-intellectualism." *(Mrs. Watson's remarks were made to an audience of educators, not to the general public, about which she is concerned—Ed.)* Too long have engineers permitted their scientific brethren to speak for them. I submit that the engineering profession has thereby given its tacit concurrence—a concurrence which should be promptly withdrawn by more positive participation in intellectual affairs.

The quotation from Updegraff's article on professional recognition contained, I believe, all the right premises, but comes to a misleading conclusion. He is quite obviously correct in his thesis on the engineer's relationship to the public, but the result of this is not lack of recognition, but rather recognition in a form different from that which has accrued to those professions in direct contact with their clients. The situation is reminiscent of a fellow who starved to death on a deserted south sea island. It seems he didn't like fish or coconuts.

We should recognize that in certain forms, the engineering profession has achieved considerable success in this matter of recognition in recent years. True enough, it has come as a result of awareness of the importance of engineering, first to national security and, as a poor second, to economic growth. Now, as a matter of fact, many engineers don't like this kind of recognition—like the fellow who didn't like coconuts—but nevertheless, there it is for what it's worth. I am always reminded of this when engineers deprecate the concept of the shortage of technical personnel. From the point of view of public relations and developing concepts in the public mind of the importance of engineering and of the engineer, this concept, in many respects, is the best thing that ever came up the pike. The individual purists who don't like coconuts have "nit picked" the concept to the point where many engineers actually feel embarrassed when they see references to their own importance in print. My thesis here is that the public can be sold—indeed it has been sold—on recognition of the engineer and his importance to national strength just as Mr. Updegraff's housewife admired the surgeon who sewed up her son's head—and for precisely the same reason. You see, the basic human drive from time immemorial has been survival. Only recently engineers have made it possible for us to begin wondering about what *kind* of survival.

W. T. Cavanaugh
New York City

To: Golf Tournament Winners

Due to malfunctioning of the film transport mechanism of the camera used at White Sulphur Springs, A.I.Ch.E meeting, the roll presumed to contain exposures of the above subjects was found upon processing to be completely blank.

I am terribly sorry.

—Editor

Dear Editor:

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—%#$×*%#$×*%!%Z#!!!!!

Mrs. Emerson Lyons
(Winner)

Reflectivity Probe

The article "Performance of Dry Solids Mixing Equipment" by J. B. Gray in the January issue of *Chemical Engineering Progress* has been read with great interest and the construction and use of the Bechtel Reflectivity Probe would seem to introduce an instrument which will be very valuable for instantaneous testing of the quality of dry mixes.

However, I believe that in using this instrument, its limitations should be clearly understood and acknowledged.

Due to static charges, small traces of moisture, roughness of surface or natural surface tackiness, most dry solids consist of aggregates, and the mixing of two or more of these materials consists not only in blending these aggregates but in breaking them down, with the aim that the final mix will approach a blend of ultimate particles.

In the article, Gray covers the mixing of dry materials ranging from 60-mesh sand down to minus 200-mesh Ilmenite and to precipitated barium sulfate of unspecified mesh. The area range from 200-mesh to 60-mesh is in the order of 1 to 11 and mixtures of particles in this range were measured by the reflectivity probe. Also, he mentions the presence of agglomerates in the barium sulfate mix in the ribbon mixer where the reflectivity probe gave better results for the ribbon mixer than for the muller, in which no agglomerates were observed.

As the nuclei of aggregates may vary greatly, I question the accuracy of the probe. I, therefore, believe that I am justified in assuming that this probe cannot differentiate between uniform mixes of aggregates and mixes of ultimate particles. It is, therefore, felt that the reflectivity probe is not accurate enough to gauge the extremely perfect mixing necessary for many of our manufacturing requirements and that tests made with it cannot fairly gauge the results which can be obtained with the mix-muller, which is used commercially in preparing practically all these high quality blends.

Mixing of this type demands crushing, smearing, and shear forces which cannot be developed in mixers of the free-fall type or in mixers having excessively wide clearance between the moving blades or between the blades and the container.

H. Leslie Bullock
New York

Mr. Gray's reply follows:

We agree with Mr. Bullock that the method of analysis and the sample size which should be used to judge the uniformity of a mixture of dry solid particles depend on the end use of the mixture. We also recognize that there are many end uses and analytical methods.

The reflectivity probe described in our paper was not designed for obtaining data which could be used to measure the uniformity of composition of very small samples nor was the probe designed as a substitute for end-use tests.

J. B. Gray
Wilmington, Delaware

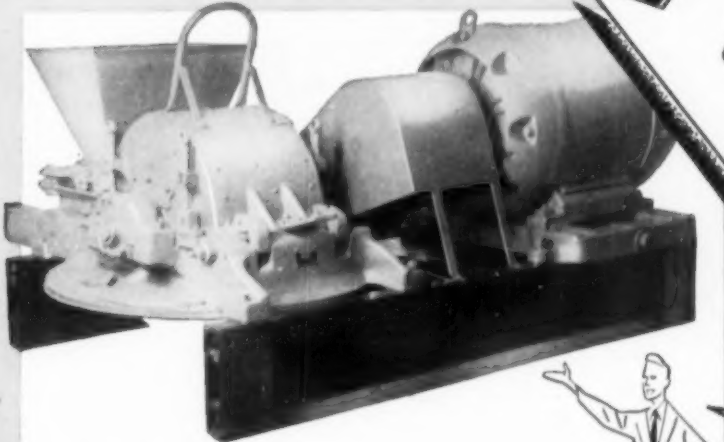
From TEST to TONNAGE...

"SCALE UP"

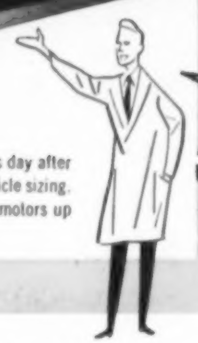
with

Mikro-Pulverizers

THE BANTAM PULVERIZER is a complete miniature grinding plant, perfect for pilot plant and experimental work. Easy and economical to operate, the BANTAM utilizes a ¾ or 1 hp motor, and has an average capacity of 75-100 lbs. per hour.



NO. 4 MIKRO-PULVERIZER
—a rugged, high-capacity mill, designed to produce specified results day after day, 24 hours a day . . . readily adjustable for speedy changes of particle sizing. MIKRO-PULVERIZERS are available in four models (Nos. 1-4) with motors up to 75 hp, and capacities to 25,000 lbs. per hour.



"ENGINEERED FOR DEPENDABILITY... ECONOMY... HIGH PRODUCTION!"

Whatever your grinding requirements, there's a MIKRO-D pulverizing unit tailor-made for the job. You'll find an economical, miniature plant, ideal for small production work . . . a choice of stepped-up intermediate sizes to serve growing production demands . . . or an ultra-high capacity mill designed to produce more than ten tons per hour! In addition, you'll discover that the quality and fineness of grind specified for your product can be exactly duplicated, in any quantity, on every pulverizer in the MIKRO-D line!

For a laboratory demonstration of the results you can expect from these MIKRO-D units, send us a product sample and your specifications. We believe you will be convinced that low-cost, dependable MIKRO-D equipment—now serving in chemical processing plants throughout the world—can put more profit in your production. Of course you are invited to write for full information on the complete MIKRO-D line.

GENUINE MIKRO-D REPLACEMENT PARTS AVAILABLE FROM LARGE STOCK WITHIN 48 HOURS.

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MANUFACTURERS OF PULVERIZING, AIR CONVEYING AND DUST COLLECTION EQUIPMENT

About our authors

HOPE FOR THE FUTURE

U.S. has reserve of up-and-coming brains and talent

The young people on these pages represent a current asset on the national balance sheet. But, far more, they represent important capital for the future. They are all talented Americans still in their 20s and 30s who have made important contributions to the fields in which they work. The names of a few of them have spread beyond their immediate fields—Perry, the boy-wonder businessman, Stellato, a potential Reuther in labor, Murphy, whose Kansas medical plan may be a model for many states. But most are still unknown, waiting for an older generation to move over and make place for them. LIFE chose these 14 not as all the best young talent in the U.S. but as a cross section, covering many aspects of the nation's work.

CHEMICAL ENGINEER Robert Roy White, 34, has been a full professor at the University of Michigan for two years. On the side he acts as consulting engineer for Dow Chemical Company and the Columbia Gas System (for which he is helping to develop synthetic fuels against the time when the national supplies of natural gas run low). Chubby Engineer White seldom rests his energetic brain. His favorite relaxation is to play several games of chess at once while blindfolded.

(As printed in *LIFE* magazine, January 1, 1951. Photo, Myron Davis—courtesy *LIFE* magazine. © 1951 Time Inc.)

Robert R. White hardly needs any biographic description over and beyond the sketch done by *Life* in 1951, when he was selected as one of the twelve most talented young men in the U. S. (above). Still vigorous (A.I.Ch.E. Professional Progress Award winner 1956) but no longer "chubby," Bob's latest contribution to his profession is the thoughtful, thought-provoking article "The Engineer and the Spectrum of Knowledge" which is based on his Boston P. P. Award lecture.

CEP's Roundtable on process control literally bulged with talent that cold night in Boston during the Annual Meeting of A.I.Ch.E. **Dave Boyd,** co-chairman of the session, is an outstanding figure in the field of advanced automatic control of chemical processes. Recently a guest lecturer at Heidelberg University, Dave is currently returning from a month's tour of lecturing in Japan as a guest of major scientific and engineering societies. At Universal Oil Products, Dave heads the group which is responsible for control system design, selection of instruments, and supervision of control system performance during start-up and initial operation

(*Continued on page 42*)

About our authors

(Continued from page 38)

of all of UOP's licensed plants. **Wayne Alexander,** who is an experienced moderator of several of *CEP's* Roundtables, is a chemical engineering executive at Monsanto's Plastics Division petrochemical operations at Texas City. He has, we presume, presided at many a conference at which proponents of various control system ideas would have to be resolved to a practical plan through Wayne's skill as a moderator. **Page Buckley,** who now is co-chairman with Dave Boyd of the A.I.Ch.E. Program Committee process control section, investigates process controllability at DuPont. Currently writing a book *Chemical Process Control,* which is to be published in '58, Page is an outstanding exponent of the dynamic analysis approach to process control problems. **Russell Aikman,** a canny Scot who came to this country several years ago after having achieved recognition for his process control development work with Imperial Chemical Industries, is making his reputation international. With Schlumberger Well Surveying Corp., Russ is presently concerned with the application of new measuring techniques (through use of stream analyzers, etc.) to chemical processes. **Fred Woods** is instruments and control engineer at the South Charleston works and headquarters engineering department of Carbide & Carbon Chemicals Co., which *CEP's* readers recognize as one of the outstanding companies engaged in large throughput, continuous operation processing. **Jack Draffen** is engaged in the development of control systems for Monsanto's Texas City petrochemical works. **Sherman Dushkes** is responsible for instrumentation of new chemical plants and refineries for Shell Development Corp. in California.

Authors of process control articles in this issue include **O. J. M. Smith,** a professor of electrical engineering at Univ. of Calif. (Berkeley), who has written a book now in press (McGraw-Hill) titled *Feedback Control Systems.* Smith, also trained in chemistry, estimates he gives 10 papers and 25 talks before society functions each year. **Ted Williams** will be remembered by *CEP* readers for his recent (Nov. '56) article on use of analog computers, manages to mix computer solutions with servo control techniques and come up with process control systems. A member of Monsanto's recently organized Systems Engineering Group at St. Louis headquarters, Ted had previously been

(Continued on page 47)

Prepared by U. S. Industrial Chemicals Co.

U.S.I. CHEMICAL NEWS

May ★ A Series for Chemists and Executives of the Solvents and Chemical Consuming Industries ★ 1957

New Polyethylene Bottle Has Built-In Sterilization

A manufacturer has introduced a self-sterilizing polyethylene bottle in which a permanent type antiseptic is incorporated in the resin at the time it's molded. The product seems to be an effective answer to an old problem: how to sterilize a polyethylene container without subjecting it to high heat.

Self-sterilization by chemical means is not new, having been used for a number of years in textiles, leather and plastics. However, the new polyethylene bottles are believed to represent the first successful use of the principle in this field. Until now, polyethylene bottles which required sterilization have been irradiated, a costly process that offers less permanent protection than many chemical antiseptics.

In the new product, a liquid germ-killer (nature not disclosed), is added to the polyethylene as it goes into the mold. As little as one gallon is claimed to render 5,000 lbs. of resin self-sterilizing for an indefinitely long time.

The new bottles are expected to find wide acceptance in the drug and pharmaceutical fields.

Methionine Plays Role In Adrenal Gland Function

A recent study reports evidence that methionine is beneficial to Vitamin C metabolism and to the functioning of the adrenal glands.

It was found that methionine increased the Vitamin C content of the adrenal gland in experimental animals. A high level of Vitamin C in the adrenals is known to help these glands function better. Vitamin C is necessary for the utilization of the adrenal cortex hormones, especially for the salt metabolism they control.

Of three sulfur-containing amino acids studied, only methionine had this effect.

U.S.I. and Mallory-Sharon Form New Subsidiary to Melt and Fabricate Zirconium

Reactive Metals, Inc. Will Concentrate on Ingots and Mill Products to Help Speed Growth of Zirconium Industry

Formation of Reactive Metals, Inc., a joint enterprise of U.S.I.-National Distillers and Mallory-Sharon Titanium Corp., marks another step in the evolution of zirconium from a specialty business into a full-fledged commercial industry. For the present, the new company will melt zirconium and its alloys and will manufacture zirconium mill products. Production will be expanded soon to include hafnium, and later to include other metals of value to the atomic energy program.

New ingot melting facilities will be constructed at Ashtabula, Ohio, site of U.S.I.-National Distillers' new zirconium sponge plant. Auxiliary facilities will be provided to insure production of sound ingots, both alloyed and unalloyed, ready for fabrication to any type of product. Mallory-Sharon's years of experience in melting and fabrication of titanium will be utilized to the fullest extent.

Will Ease Supply Situation

Formation of the new subsidiary will make it possible for users to buy zirconium sponge or platelets from U.S.I.-National Distillers, or finished ingots, billets or mill products from Reactive Metals at firm prices with firm delivery dates.

Common sizes of ingots and billets will be carried in stock. This will greatly reduce existing procurement delays.

U.S.I.-National Distillers has lowered the price of zirconium sponge considerably through technical advances, but the company feels that similar progress must be made in melting and fabrication before zirconium

MORE

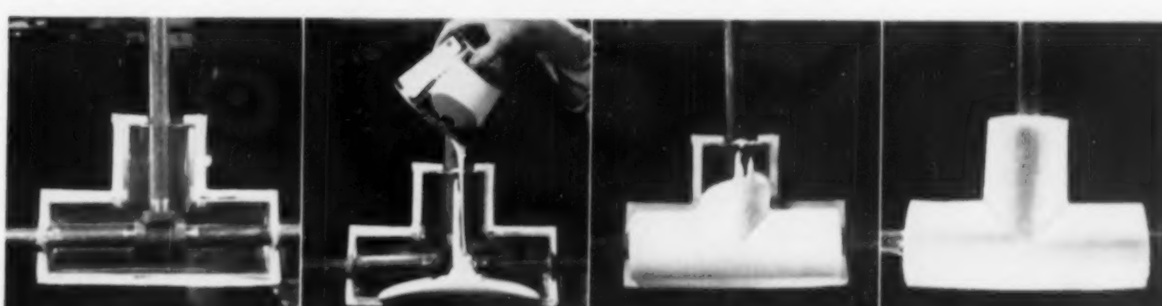
Titanium Gets Chrome Coat

A method for electrodepositing a chrome coat on titanium has been developed by the National Bureau of Standards after years of research on the problem of bonding the two metals. The purpose of the coating is to overcome the tendency of titanium to seize or gall in loaded contact with itself or other materials, and to prevent oxidation of the metal at elevated temperatures.

Availability of coated titanium should result in greater use of the metal in many equipment applications where seizing and oxidation have presented difficulties.

Up until now researchers have been unable to bond any metal to titanium, due to the formation of an oxide film on the titanium surface during handling in the bonding operation. With the new method, the oxide film is removed from the titanium surface and is immediately replaced by a fluoride film. Oxide can no longer form. When the titanium is placed in the chrome plating bath, the fluoride film dissolves away, leaving a clean surface and allowing the chromium to bond directly to the base metal.

Pipe Joint Gets Urethane Foam Insulation In Place



Versatile urethane foam is formed on the job, makes insulating easy. Transparent mold is set up around pipe joint. After mixing polyisocyanate with polyester, mix is poured into mold. U.S.I. ISOSEBACIC Acid can be used as intermediate for polyester component.

Urethane polymer is formed by mixing of the two chemical components and carbon dioxide gas is given off during reaction, causing polymer to foam in place. Polyurethane foam hardens almost at once, and mold is removed. Photos courtesy Napco Chemical Company.

May ★ **U.S.I. CHEMICAL NEWS** ★ 1957

New U.S.I. Booklet Updates Information on Sodium Dispersions

A new 44-page technical bulletin just released by U.S.I. contains much new information on techniques and equipment for using sodium dispersions in pilot plant and full scale reactions. U.S.I., a pioneer in the development of sodium dispersions and their adaptation to commercial use, was the first to present to the chemical industry a technical bulletin on this interesting branch of sodium chemistry.

The new publication describes the most recent advances in engineering techniques and equipment to achieve higher yields and reaction rates, improved reaction control, economy of reagents and new uses of sodium dispersions. Methods for converting liquid sodium to dispersion form on a commercial scale are discussed, as are continuous processes.

Sodium dispersions and high surface sodium (sodium-coated particles) are two forms of metallic sodium with a tremendous amount of active surface area. These forms give sodium greater usefulness in a growing number of chemical reactions.

The comprehensive new technical bulletin, "Sodium Dispersions", is available on request from U.S.I.

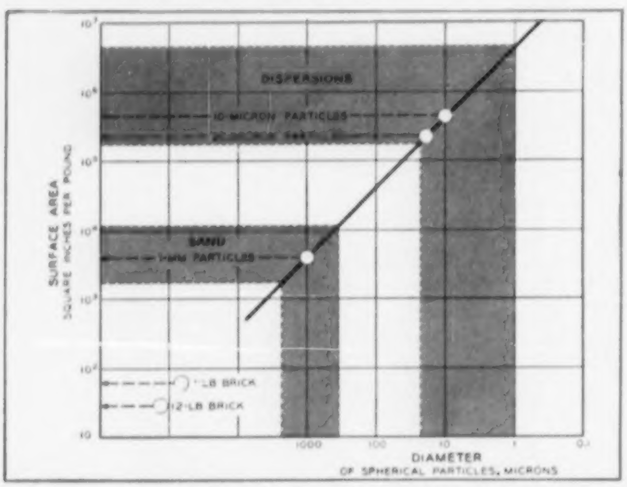


Chart reproduced from booklet shows available surface areas for reaction of several forms of metallic sodium. Dispersions offer about 100 times as much area as sodium sand and about 10,000 times as much area as uncut sodium bricks. High-surface sodium (sodium-coated particles) can offer even more surface area per pound of sodium.

CONTINUED Subsidiary

can fulfill its proper role in the metals and chemical industries. This purpose is to be served by the new jointly owned subsidiary. Backed by the technical and financial resources of the parent companies, it will devote its efforts solely to the processing of zirconium and other reactive metals.

TECHNICAL DEVELOPMENTS

Information about manufacturers of these items may be obtained by writing the Editor, U.S.I. Chemical News.

Non-toxic developer for blueprints is said to combine advantages of potash or hydrogen peroxide with these additional features: does not clog drains; washing after development may be omitted; excellent recovery from fading. **No. 1230**

New technical data sheets on trimethyl and triethyl aluminum have just been published. Both compounds are used as fuel ignitors in ram and turbojet engines, as polymerization catalysts and intermediates. **No. 1231**

An atomic flashlight said to provide light for many years without the aid of batteries or external power sources has been developed. It uses an essentially non-hazardous radio-isotope. Can be made in many sizes and shapes. **No. 1232**

Over 50 reactions of fatty alcohols are described in detail in a new 16-page brochure. Technical data on unsaturated aliphatic and saturated aliphatic alcohols are given, and the bibliography cites 70 references. **No. 1233**

Polyethylene pipe with ribs that protect the pipe wall and increase its resistance to burst is now being fabricated. The closely spaced ribs extending lengthwise of the pipe are also said to facilitate stacking of coils. **No. 1234**

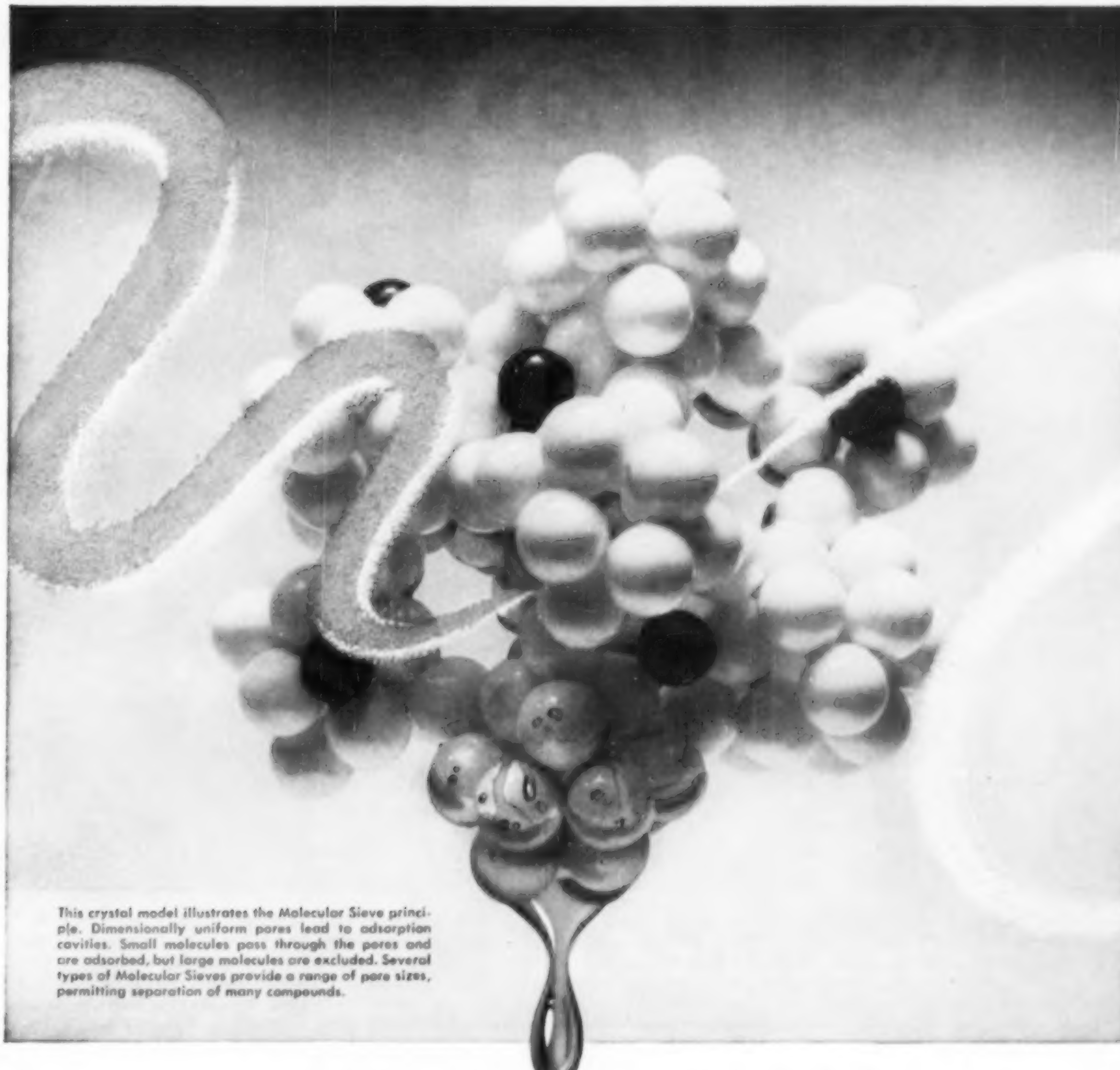
Pigment Extenders, Flatting Agents and Filter Aids are discussed in a brochure which also contains many formulas for solvent and water-thinned paints. Each formula is on a separate sheet for easy removal and binding. **No. 1235**

Nitrogen-15 enriched to 95% is now available in a number of reagent chemicals. This important tracer isotope has not been previously available in higher than 60% purity. **No. 1236**

Sodium tetraphenylboron, a popular reagent for potassium determinations, is now offered as a high-purity reagent with individual lot analyses. The compound has a minimum assay of 99.5%. **No. 1237**

Isotope Boron-10, until recently restricted to AEC requirements, is now available in kilogram amounts for civilian use. The material, which resembles powdered graphite, is valued at nearly three times the price of refined gold. **No. 1238**

A de-watering press embodying new and novel features has passed pilot model tests and is available in commercial models. It is said to embody all advantages of a hydraulic press, yet is continuous in operation. **No. 1239**



This crystal model illustrates the Molecular Sieve principle. Dimensionally uniform pores lead to adsorption cavities. Small molecules pass through the pores and are adsorbed, but large molecules are excluded. Several types of Molecular Sieves provide a range of pore sizes, permitting separation of many compounds.

Now . . . SELECTIVE Separation with MOLECULAR SIEVES

LINDE Molecular Sieves, a new *class* of adsorbents, offer unique performance in product purification and recovery. These crystalline zeolites provide selective separation of gas and liquid mixtures in *three* ways . . . difference in molecule size . . . or polarity . . . or carbon bond saturation.

Selective removal of contaminants, even in trace amounts, is possible at temperatures up to 300° F. Selective recovery of valuable stock is often accomplished without regard to relative boiling points. Co-adsorption eliminates extra processing steps by removing several impurities simultaneously. High capacity is realized through a wide range of operating conditions.

Typical uses for Molecular Sieves are the separation of n-paraffins from iso-paraffins and cyclics . . . extraction of olefins from refinery streams and top gases . . . removal of catalyst poisons from olefins . . . sweetening of natural gas and reformed hydrogen . . . purification of annealing gases.

For a descriptive booklet, "Molecular Sieves for Selective Adsorption," write Dept. CP-5, Linde Air Products Company, A Division of Union Carbide and Carbon Corporation, 30 East 42nd Street, New York 17, N. Y.

Linde
TRADE MARK
MOLECULAR SIEVES

The separating force produced by this Merco centrifuge is made practical by the strength of its high speed rotor bowl, machined from cast stainless steel with a high nickel content, produced by Electric Steel Foundry Company, Portland, Oregon. Weight of the all-stainless steel rotor assembly on the unit shown above totals 1600 lbs. This centrifuge has a large continuous through-put capacity. In many plants, Merco units run continuously for 24 hours, virtually unattended. Manufactured by Merco Centrifugal Company, San Francisco, California.

Up to 9000G's developed...

thanks to strength of rotor cast in stainless ... that licks corrosion and erosion

Merco Centrifugal Co. tested scores of materials for their centrifuge rotors. And found what they needed in cast chromium-nickel molybdenum stainless steel (ACI Type CF-8M.) These castings safely answer the high strength demands, and in addition, provide resistance to both corrosion and erosion.

Read what a typical customer reported about the performance of a Merco rotor machined from this cast stainless steel containing 10 to 12% nickel:

"... shows no signs of corrosion after 12 years' service in slurries of warm weak sulfurous and lactic acids, SO_2 vapors, alternate wetting and drying, with liquid and solids passing over the metal surfaces at very high speeds."

Despite corrosives and suspended solids, this rotor has operated for more than a decade with no apparent damage from erosive action. Many similar records confirm that Merco engineers made a wise choice, years ago, when they selected Type CF-8M stainless castings for rotors.

Alloys containing nickel may help *you* strengthen equipment, combat corrosion and erosion, or meet other specific needs. When you face a metal difficulty, send us details. We'll submit suggestions based on wide practical experience. Write for List A of available publications. It includes a simple form that makes it easy for you to outline your problem.

INCO THE INTERNATIONAL NICKEL COMPANY, INC. 67 Wall Street New York 5, N. Y.

About our authors

(*Continued from page 42*)

Amundson

Comings

prominent as a representative of the Air Force Institute of Technology, presenting papers in the field of computer application. **Neal Amundson** combines chemical engineering with mathematics (higher order) to pave the way for the more advanced systems of control which are ultimate. Head of Chemical Engineering at Univ. of Minnesota, Neal was a Guggenheim Fellow and Fulbright Scholar at Cambridge.

Ed Comings, head of Chemical Engineering at Purdue, writes with **C. L. Coldren** about a new type of jet spray dryer. Ed will be remembered as Walker Award winner for 1956, for his work in the field of high pressure technology. Describing their currently-reported work as derived from wartime aerosol thermo-generators, their investigations have taken them into studies of the behavior of free jets, a jet in a duct, and static pressure distribution in jets.

R. J. Hengstebeck has worked almost 14 years in process design, is currently evaluating research projects for Standard of Indiana.

L. Burris and **I. O. Winsch** have been at Argonne, engaged in separations process development work, for nearly 10 years. Burris heads the pyrometallurgical process development group, and Winsch is in charge of work using magnesium for extracting plutonium.

Fred G. Hammitt is a research engineer in the Engineering Research Institute at Univ. of Michigan.

E. L. Piret, who with **Schulz** and **Cooke** has written on crushing, likes to approach a chemical engineering problem from the most basic viewpoint possible. As professor of chemical engineering at Univ. of Minnesota, Ed holds a great many honors from European institutions, is currently organizer and editor of the volume *Chemical Engineering Around the World,* which will be one of the outstanding products of A.I.Ch.E.'s 50th anniversary next year.

Burris

Piret

REPUBLIC

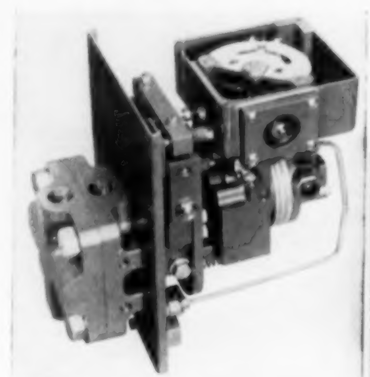
announces a

double break-through

in pneumatic transmitter rangeability!

TYPE VP

Pressure Transmitter
Standard Ranges
0-150 to 0-4000 psi
0-60" H_2O to 0-150 psi
0-1½" to 0-60" H_2O



TYPE VDP

Differential Transmitter
Standard Range
0-15 to 0-300" H_2O

- **Null-balance-vector design permits 20-to-1 range adjustment without re-setting zero!**
- **Suppression of range lower limit simply adjusted up to 50% of span!**
- **New compactness and weight saving solve most location problems.**
- **Low air consumption.**
- **Simplified, accessible mechanism for quick and easy servicing.**

Republic has *literally* figured all the angles to bring you this new "family" of pneumatic transmitters for pressure and differential pressure. The null-balance-*vector* units are compact, easy to install and adjust, and permit range changes far beyond any pneumatic instruments previously available to industry—and *without changing* parts. You need only a screwdriver and reference gauge to change either the upper or lower range limit!

Adjustment time is radically cut since re-zeroing of the instrument is seldom needed when the upper range limit is changed. Unusually large changes in plant operating conditions can be accommodated quickly and without new or modified equipment, simply by loosening a set screw and moving one linkage component.

Republic Type VP and VDP pneumatic transmitters normally provide standard 3-15 psi output signal pressures. Air consumption is only 0.2 scfm since air flow virtually stops as soon as the transmitter balances each input signal change. And all Republic null-balance-vector instruments have top sensitivity *and* stability. Lightweight tension members in the balancing linkage respond quickly to pressure or differential changes and do not overshoot or "hunt" the balance point.

Whether your plant conditions change frequently or you just want the best sensitivity, accuracy and reliability available in pneumatic transmitters, you should get the full details on Republic Type VP and VDP transmitters.

WRITE FOR REPUBLIC FOLIOS NO. 56-12 AND 56-13A TODAY...and keep an eye on Republic for new developments "in the works" now to help you with your most critical operating instrument problems.

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Marginal notes

Tools & trends

Automation in Business and Industry, by E. M. Brabbe (editor). Wiley, New York, 611 pages, $10.

Here is an easy-to-understand compilation of chapters dealing with various aspects of automatic control of wide interest to chemical engineers. Leading off with an introduction by the well-known engineer and educator L. M. K. Boelter, this volume is based on a series of lectures given in an engineering extension course during the spring of 1955 at the University of California. In picturing the present state of the field, *Time*-cover man Simon Ramo of Ramo-Wooldridge Corporation cautions, "anyone who is foolhardy enough to challenge the idea that the replacing of man's brains will be the top industry in the nation some years hence is in danger of having his brains among the first to be replaced . . ." Editor Grabbe, of the same firm, wisely introduces the reader to the systems concept through dealing first with mental images, and then with a glossary—which is pertinent in a field already endowed with new words (*cybernetics*) as well as jargon (noise = errors in systems).

Getting further down to facts, there is a chapter on feedback control systems. The characteristic devices used for industrial control are next described, which leads to a 200-page section on computers and data processing. Analog, digital, and analog-to-digital units are described. The remainder of the book, almost half, is devoted to applications. A chapter (35 pp.) in this section is devoted to process control in the petroleum and chemical industries, by C. G. Laspe of Shell Oil, Wilmington, Calif. Laspe's introduction to his subject appears in terms of the real methods in current use. His discussion of systems leads to the servo techniques for evaluating the dynamic characteristics of process equipment, and he attributes rapid advancement in this to the past two years. Briefly describing the same concept is the discussion in the *CEP* Roundtable elsewhere in this issue. "The ultimate goal," concludes Laspe, "in the application of frequency response techniques to controlling equipment and industrial processes is to catalog all the transfer functions of each component part of the many industrial control systems. This . . . will provide a ready reference for the systems engineer, allowing him to predict ahead of time, while the process is still on the drafting table, all of the control functions which will be needed, how the proposed control system will operate, and finally the cost of the control system . . . Much more work needs to be done . . . before this catalog can be finally compiled."

Encouraging Scientific Talent

"A Study of America's Able Students Who are Lost to College and of Ways of Attracting Them to College and Science Careers." Charles C. Cole, Jr. College Entrance Examination Board, New York (1956), ix +259 pages.

Reviewed by Warren L. McCabe, Brooklyn, New York.

To a large and growing list of literature on manpower problems in engineering and science this book is a valuable addition. Its main themes are based on the results of a national study questionnaire administered by the Educational Testing Service of Princeton, New Jersey.

The first half of the book is a summary of previous studies made in this general field. These chapter headings

(*Continued on page 52*)

Marginal notes

(Continued from page 50)

include an introduction on science and scientists; scientific ability and its identification; scientific ability, its supply and demand; the loss of talent from high school to college; deterrents to the production of scientists; and potential factors encouraging careers in science.

The rest of the book is an analysis of the data obtained in the questionnaire and a summary of the conclusions and recommendations.

Emphasis in the first half is placed upon the importance of the family background, family guidance, and family encouragement for college-going. The loss in teaching power in the high schools, especially in mathematics and science, is described and properly deplored.

The problem of "motivation" is explored. The point is made that motivation has its origin in early life and if large numbers of unmotivated high-ability high school graduates each year are to be attracted to scientific and other professional careers, the promising students must be identified, guided, and stimulated much earlier than their senior year in high school. Such programs must include much more than an offer of a scholarship. Although there is a continuous process of making choices, another decision is made when the high school student decides on how much mathematics and science to take. Another milestone occurs, of course, when at the end of high school the graduate decides whether or not to go to college. Once these decisions have been made, the largest loss of potential engineers and scientists has already occurred.

Data and conclusions resulting from the questionnaire itself are too voluminous to be adequately covered in a short review. Several results having to do specifically with engineering and natural science may be noted. First, engineering does well in competition with all other fields in the vocational aspirations and desires of high-ability students, engineering being the idealized choice of about 26% of the high-scoring boys. Another finding is that, provided adequate scholarships are available specifically directed to engineering, 60% of the high-scoring seniors would be attracted to engineering and 50% to physical science. The important conclusion emerges from these figures that engineering and physical science have a great deal of appeal to high-ranking students and an even greater potential appeal if proper financial aid were available.

The thinking of leaders in the chemical industry and their projections for this year have been revealed in annual meetings (held mostly in April) where executives report to their stockholders and usually give out earnings reports for the first quarter.

Annual meetings which not so many years ago were held quietly in small rooms with only a handful of stockholders present have now become major productions with attendance running into thousands for some of the big companies. At these meetings today managements pretty well let their hair down in discussing plans, hopes, and the outlook.

Quiet Optimism

Generally speaking, managements are quietly optimistic about the outlook for this year, expecting moderate gains in sales and, in most cases, slight gains in profits. It becomes more and more plain, however, that for the immediate future no big jumps in earnings can be looked for, and most firms are quietly laying plans and spending money on plants and research with their sights several years off.

There is certainly a marked trend to spend more and more money on research, even though industry budgets for this essential operation are already huge. Increases in research budgets, however, are obviously a direct drain on profits and in some companies are actually a factor in holding down current earnings against hopes for benefits in the future.

With reports for the first quarter now available, it is evident that the year is starting off on a rather subdued note as far as earnings go. A list of about 25 companies in the chemical field shows that all but four showed gains in sales—some as much as 10 to 15 per cent, over a year ago. However, about half the companies reported a drop in profits from the first quarter of 1956 and also from the final quarter of 1956. The declines from a year ago average around 20 to 25 per cent, which is not exactly cheerful reading.

One of the most drastic declines was shown by the Koppers Co., which is in other fields besides chemicals. Koppers profits were down nearly 50 per cent from a year ago. The reason was weakened prices in plastic materials—styrene and polyethylene.

Widening the Profit Margin

All this has further spurred the efforts of managements to do something about cutting costs, since they see little hope of doing anything about raising their prices significantly. The chairman of a medium sized company states his problem and the problem of the industry this way: "We are having difficulty in maintaining our profit margins. Competition is increasing in the chemical industry and it is becoming more and more difficult to pass on increased costs by raising prices. We are putting into effect the most concerted company-wide cost reduction and savings campaign we have ever undertaken."

An economy campaign is one direct and obvious way to cut costs, but it is hardly the answer to the long range "cost-price squeeze" problem. One firm with a large segment of its business in the textile fiber field paradoxically improved its profits slightly by cutting prices, thereby getting enough additional volume to produce larger profits even though margins were lower. But this is an expedient that cannot be successfully used in the case of most chemicals—especially older products—because lower prices would be unlikely to produce any more volume. Industry policy, of course, is to try to bring down the prices of newer products as soon as production reaches commercial scale.

Research Pressure

There is a strong trend toward "crash" programs in research to develop really basic technological improvements that will make important reductions in costs. Looking for better ways to do things is traditional in the chemical industry, but the pressure is now greater than ever.

One recent example of successful technical advance is a method for making carbon articles in a few minutes instead of over a period of weeks. This will go far toward overcoming the higher wage problem and is also equivalent to an important increase in plant capacity. Other examples are improvements in electric furnace techniques which double the furnace capacity and an improvement in the conversion rate of polymerizing polyethylene. Another new process now well on the road produces synthetic vitamin A starting with acetone instead of using the costly natural material, lemon grass oil.

Another basic approach is to attack the raw material problem by acquiring reserves of oil and gas to assure a supply of hydrocarbons for petroleum chemicals. Several large chemical firms now have big oil reserves—either acquired directly or through merger with other firms. The problem is pointed up by the fact that the cost of hydrocarbons and derivatives is up about 110 per cent in the past decade, whereas the price of chemicals is generally down. One example is benzene, which is up from about 15 cents a gallon to about 36 cents a gallon over a ten year period.

The trend toward trading-up by making things closer to the consumer sounds like an obvious and simple expedient, but it is set with many pitfalls. Several chemical firms have done it successfully. Others have found to their grief that their personnel does not think along consumer lines and that they are not set up to battle with non-chemical firms in this highly competitive territory.

CEP

opinion and comment

A JOB WELL DONE

The 1957 issue of *The Chemical Industry Facts Book* is out. Published by the Manufacturing Chemists' Association, this annual volume presents statistics derived from the member companies, which represent about 90 per cent of the productive capacity of the U. S. chemical industry. This year's edition contains a good deal of information which comes from a survey of 1956 activities.

Construction is shown to be at a continuing high level. In 1956 the industry completed 354 domestic chemical construction projects costing more than $1.1 billion. For the next two years (1957 and 1958) more than $ 2.5 billion will be spent on 406 additional projects in 44 states by 327 companies.

New research facilities are impressive. In 1956, facilities costing $42 million were completed, with $37 million more under construction and $16 million definitely planned, for a total of $96 million. Industry spending for research and development (currently in the neighborhood of $400 million each year) prompted the following comment by the National Science Foundation in 1956: "'The chemical industry far exceeds all others in the magnitude of its basic research program." In a 1953 survey, the chemical industry was found to be spending for basic research 25 per cent of the total of all industries in the U. S.

Safety, always of prime importance, is shown in 1955 to be exemplary, with the frequency rate (for industrial accidents in the chemical industry) 58 per cent less than in 1946; the severity rate was reduced by 23 per cent in the same period. At the same time, while employee hours of exposure for MCA member companies went up by 95 per cent over 1946, industrial injuries were down by 17 per cent.

Always noted for its stability with respect to labor turnover, the industry in 1956 had a record of about 1.4 per 100 employees, whereas manufacturing in general averaged about 3.5.

The chemicals and allied products industries are shown to have employed 8.7 per cent of the country's scientists and engineers. A sober note arises, however, in consideration of the estimate that the industry will have a deficit, by 1965, of some 93,000 skilled persons unless the supply is substantially increased. In this connection, the industry, with the coordination of MCA, is conducting a high level aid-to-education program which each year is widely publicized during Chemical Progress Week.

Why is the chemical industry so successful, such an epitome of progress, so typical of the American dream? There are many reasons, some of which lie far beyond the scope of analysis here. Without a doubt, the chemical industry is giving the American people what they want. But over and above this, it is clearly evident that the chemical industry is run by people who have bold imagination, the courage to carry out their ever more expansive plans, and who know how to acquire and make good use of properly trained men for management roles. Putting a yardstick to the technical competence of management seems, at first, difficult—if not impossible. On the other hand, one of the statistics in the Facts Book seems to do just this: "In the 1955 survey, 75 companies reported more than half of their executives have degrees in science or engineering, or both." Perhaps this helps to explain, in part, the outstanding contributions the chemical industry has been able to make to the greatness of our country.

—JBM

• **PLACE:** Boston, A.I.Ch.E. Meeting, hotel ballroom.

• **TIME:** early evening, Monday, December 10, 1956.

• **PURPOSE:** to discuss in front of an audience new techniques for achieving improved automatic control of chemical processes. These new techniques to be related to existing practices, existing plants.

• **PLUS:** "crystal ball" session on what the chemical engineer will be expected to accomplish in the future.

• **CAST:** six outstanding men in the fields of practical and advanced chemical process control. Chairman: a seasoned engineering administrator who has coordinated the process, control, maintenance, and other functions which together make possible the modern petrochemical (continuous, large throughput) type of plant—**Wayne Alexander,** Associate Director of Engineering, Plastics Division, Monsanto, Texas City, Tex. **Dave Boyd,** Head, Instrumentation Department, Universal Oil Products Co., Des Plaines, Ill. **Russ Aikman,** Instruments Sales Engineer, Schlumberger Well Surveying Corp., Richfield, Conn. **Page Buckley,** Research Associate, Chemical Engineering, DuPont Experimental Station, Wilmington, Del. **Jack Draffen,** Instrumentation Group Leader, Plastics Division, Monsanto, Texas City, Tex. **Sherman Dushkes,** In Charge, Instrumentation Group, Shell Development Co., Emeryville, Calif. **Fred Woods,** Instruments and Control Engineer, Union Carbide Chemicals Co., So. Charleston, W. Va.

The three articles which follow this Roundtable demonstrate three degrees of application of dynamic analysis techniques to chemical process control problems. The **Smith** article (page 217) shows how basic methods of dynamic analysis are applied to set up a problem for solution by calculations common to any engineering department. The **Williams** article (page 220) demonstrates how to approach and set up for solution the type of problem that is frankly best solved through the use of a computer. The **Amundson** article (page 227) demonstrates how to analyze a control problem using mathematical techniques (a term used in intentional contrast to "calculation solution") descriptive of the various basic phenomena involved. Numerical solutions to Amundson's equations require the use of a computer.

—Editor

PROCESS CONTROL ROUNDTABLE

THE CONCEPT OF THE UNSTEADY STATE

To open the discussion, Chairman Alexander asked for a definition of the unsteady state concept:

Aikman: The so-called *unsteady state* is really a part of all of these control problems. In general, plants are designed today for a state of static equilibrium. The only reference to the unsteady state that one would normally find in the textbooks is under the rather special problem of starting up a batch. Or, one may occasionally come across some odd problem in unsteady heat diffusion through a solid. But, in fact, a controlled plant is one which is controlled by instruments and is always in a state of dynamic, rather than static, equilibrium, and the whole economic success of the process depends upon the maintenance of this state. The adequacy of control obtained, in fact, depends much more on the dynamic properties of the plant than on the static properties.

Draffen: We design plants for steady state operation but this steady state doesn't occur by itself. The steady state has to be imposed upon the plant, and we have to apply corrections to the plant continually to counteract the various disturbances that tend to drive the plant away from proper operating conditions. Thus, although the plant is operating steady state, the controls are operating on the unsteady state, and it is very important in process control design to consider how equipment reacts to changing conditions.

Alexander: Could we get into how control systems are engineered at present?

Dushkes: The process engineer designs his process on the basis of steady state considerations. He is not concerned with the unsteady state. Dynamic analysis, generally, plays no part in his design.

When he starts to prepare a process diagram, he will generally indicate the variables which he thinks ought to be controlled—say a temperature here and a pressure there, and so forth.

This he thinks is necessary in order to maintain the steady state conditions upon which he predicated his design. At this point the control engineer, who may now for the first time be finding out that this project is on the books, receives a process flow diagram and begins to consider the unsteady state. From the unsteady state standpoint, he first has to decide whether the indicated variables need to be controlled (and if so, how) and second, whether any other variables need to be controlled, ones that presumably aren't already indicated. Also, he has to decide whether it is justified to conduct a dynamic analysis on any part of the process.

Now he doesn't do this automatically. Dynamic analysis is laborious, time-consuming, and costly. He has to justify in his own mind and in management's that this needs to be done. If he decides that dynamic analysis has to be undertaken, he must get the necessary data on the unsteady state process behavior, and believe me, this is not an easy job. The chemical engineer finds it pretty hard to get this information.

One of the most important things that comes out of this (and it is one of the things that Russ Aikman mentions) is that the chemical engineer, learns more about the process unsteady-state behavior.

Also, I should mention at this time that studies may be carried out to determine what analyses may be properly done by continuous analyzers, so that they can be tied into the existing plant controllers.

Finally, a detailed instrument and specification sheet is drawn up, and such details are spelled out as are necessary. At this point, the instrumentation is far enough advanced so that it can be submitted to a contractor for the detailed design and construction.

Woods: The instrument engineering people generally set the process on a flow sheet after a good deal of the equipment is already designed, on order, and perhaps in the process of delivery.

One of the things that we are faced with all the time is the fact that there is tremendous push on these new processes as they are coming out, and consequently we are not able to take the time to perform lengthy analyses. We, therefore, generally end up hanging instruments on a process that has been designed strictly from the process point of view.

Dushkes: Often in the past the fact has been lost sight of that the frequency response stems from the differential equations describing the process. It happens that the Laplace transformation provides one of the most convenient means of manipulating the differential equation; the frequency response is, in turn, the solution of the Laplace transformation for sinusoidal inputs to the system. The Laplace transformation could be solved for other inputs as well.

INTEGRATING MODERN CONTROL THEORY INTO DEVELOPMENT AND DESIGN OF NEW PROCESSES

Alexander: We've had a good deal of discussion on how process control systems are most often designed now. Does anyone have any suggestions on how to fit modern control theory into the development and design of new processes?

Draffen: Frequency response is simply one way of rating equipment with respect to how it responds to changing conditions. If you want to know how something will respond, you impose a change on it. In frequency response you impose a cyclic oscillatory change; or you could just as well apply a step change or sudden impulse.

Buckley: I have a few comments, Wayne. First of all, I think for best results you ought to start off at the testing stage. Sometimes at this point an attractive process may be abandoned because it looks unstable or impossible to control, but as the guided missiles manufacturers have pointed out, it's often possible, by using modern system control techniques, to tame a fast reaction. So, if the research at this stage is sufficiently thorough, the process designer may be able to prepare cost studies which would compare two types of processes: one, a fast process with low process equipment investment and relatively high control system investment; and, two, a slow process with higher process equipment investment and lower instrument investment. It ought to be noted that it may not be possible to run the first kind of process on manual control. Now, once you've decided on a basic process, there are three main steps to be followed to arrive at a good control system.

The first step is to make an overall high-spot dynamic analysis of the process. This will give you three things:

- the critical control factors;
- a preliminary indication of optimum control schemes; and
- approximate sizes of surge tanks or blenders for damping out disturbances in pressure, flow, temperature, composition, and such.

The second step is to make an evaluation of tentative control schemes.

The chief objective here is to eliminate what might be called impossible control systems which turn up in practically every new plant. There are ones which will not work on automatic, and they come about for a variety of reasons: sometimes the controller selected doesn't have a wide enough throttling range or a slow enough reset rate; sometimes one of the components in the control system (and this could be part of the process) has a resonant frequency close to the resonant frequency of the control system itself; there may be excessive friction or hysteresis in the valve; or perhaps the control system works for only a very narrow range of process conditions.

The third and final step is to make cost vs. performance studies.

If you do this for each of the proposed control systems, these studies will optimize (with respect to cost) alternative schemes for controlling each process variable, and also alternative choices for hardware and hardware arrangements for a given scheme. Now finally, I'd like to make three observations about *quantitatively* designed control systems in comparison with *qualitatively* designed control systems. You can usually get sharply increased performance for a minor increase in investment, you can often get better performance for less cost; and if performance is not critical, you can usually design a simpler and cheaper system.

Draffen: Well, Page didn't say how he was going to go about doing this dynamic analysis, but the immediate thing that comes into mind is setting up differential equations for the system, and solving them by some technique. This is perhaps the fundamental way of doing it, but it is also the difficult way. One thing for which I would like to make a pretty strong point is that sometimes quite simple calculations are useful. There are a number of approximate methods that can be applied to give results to maybe 30, 40, 50, or even 100% of engineering accuracy. This is a lot better than no calculation or estimate at all.

Draffen: We made one analysis for a system we were going to build in which we made the Ziegler-Nichols assumptions that we could represent the process by a first-order time constant plus dead time. This happened to be a *p*H control and involved a mixing reactor. We made a little model of the mixing reactor out of glass, about 1½ in. in diam. and 2 in. long. We ran water through it, injected dye into the water stream, and clocked it with a stop watch in order to get the dead time. We spent a lot more time arguing about how we could shorten the analysis than we did in actually doing it.

Boyd: We have a setup at Universal, where the instrument department is actually a part of the process department, which is a big advantage. We are not the differential equation type. We probably specify in a year's time on the order of 4,000 control systems, so that we could not afford to make an analysis—either mathematically or by frequency response—of each of the units we put in. However, I think that by getting periodic experience on new problems (for instance, the fractionation unit which I have described) we have a powerful tool for thought in analyzing a control system. I think we could fairly analyze any similar control problem if we had only information pertaining to the top region of the column including the condenser, and the external and internal reflux. The whole thing falls flat on its face if we try to go further down into the column. This is the subject of a whole symposium. But the point I want to make is that, with a relatively simple procedure, we do have a system that can analyze, give us a tool for thought, orient our thinking, and handle the problem without an undue amount of engineering time spent on a problem.

Woods: One more reiteration of this—referring to the example of the *p*H control system: had someone made a dynamic analysis of this system before it was installed, the fact that he

arrived at a 3,000 per cent throttling range would have made it perfectly obvious that it was an impractical installation. What if he had been off as much as 50 per cent? Even then, the throttling range would have been 1,500 per cent, which is still out of reason from a practical point of view. The point we are trying to make is that one needs only a ball park answer that will tell him if the system will be controllable or uncontrollable and then perhaps stable or unstable. That is all.

Draffen: The pH control and spray dryer examples are all in the class of making measurements on existing processes. The equipment was already in existence. And, when the equipment is in existence, it is then possible to make measurements on it, to find out what it is able to do dynamically, and to design to your heart's content. However, if the equipment is not in existence, and you want to make a dynamic analysis, you have to calculate, estimate, or get out your crystal ball in order to find out what the dynamics may be.

Dushkes: I'd like to say something of a practical nature regarding carrying out dynamic analysis. If the problem is anything more than trivial in nature, it will in all probability benefit the control engineer considerably to

THE FREQUENCY RESPONSE TECHNIQUE

D. M. Boyd | Universal Oil Products Co., Des Plaines, Illinois

The problem up to now has been one of obtaining dynamic information on plants with reasonable effort, and at a level that most engineers can use. Further, the problem has involved the use of differential equations, which is beyond the ability of most engineers, including myself. But a new method has been developed which I find, and many of my associates working in the field of control of chemical processes also find, makes possible practical dynamic analysis. This new method is called *frequency response.*

To describe this method in brief, simple terms, I might begin by referring to the system of temperature control (Figure 1) through the use of a pneumatic control valve, so calibrated that the outlet temperature of the system with 9 lb. of air on the valve is 900 degrees. Then, with 9½ lb. air, the temperature goes to 950 degrees, or with 8½ lb. air, the temperature comes down to 850 degrees.

If the air pressure on the valve is so varied at hourly intervals, we know that the outlet temperature would vary hourly from 850 to 950 degrees. However, it is easily realized that if the air pressure would be so varied at 10 times each second, the outlet temperature would probably remain constant.

Consider another example: in Figure 2 is shown a simple level control system where a control valve regulates flow into a reservoir which has a given capacity, C_1, which leaves through a restriction, R_1, into a second reservoir. As we change the air pressure in the control valve P_1 in a cyclic manner, we find that the level will rise and fall as described earlier. L_1 at this point—at zero frequency or extremely low frequency—will follow along right in phase with the input pressure. However, as the frequency of the air pressure charge to the central valve increases, we find that eventually the amplitude of the level change will decrease. With the single-capacity level control system described, the response of the level will halve every time the frequency is doubled (Figure 3). At the same time as the amplitude of the level decreases, we find that the time of maximum level will no longer coincide with the time of maximum pressure loading on the valve. In other words, it has shifted in phase. The fact that it shifts in phase determines the amount of control that can be obtained.

In order to understand this, suppose we consider an example that most engineers are familiar with, namely a child in a swing. If we wait until the swing comes all the way back and then push with as much energy as the swing lost on the previous swing (due to air friction or other losses) we will find that it will continue at a constant amplitude. However, if we apply the same amount of energy while the swing is still moving backwards, we will find that it will gradually stop swinging. Naturally, this is what we would like to have the plants do. We would just as soon not have them keep swinging. In order to see how much "push" or control we can put into our processes, we plot the magnitude ratios of the plant response vs. time (Figure 4). As in the case of the swing, we will apply the push before the dead center point (or 180 degree point). This is usually chosen at the 145 degree phase shift point. By projecting up from the 145 degree phase shift point to the magnitude curve we can tell how much energy the process will lose at this frequency and consequently how much gain can be used in the controller, or in other words, what the proportional band settings will be for stable control.

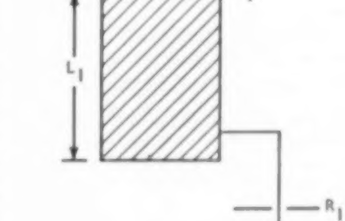


Fig. 2.

By means of this fairly simple graphical solution we have determined the settings of our controller without the use of any involved mathematics. This is the big advantage of the frequency response technique. It enables us to put controller performance on paper in a way that most engineers can understand.

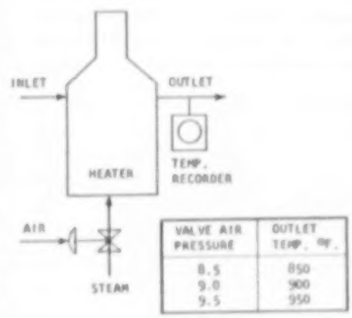


Fig. 1.

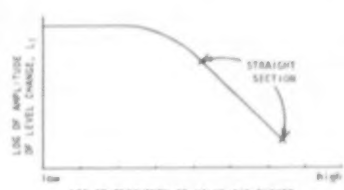


Fig. 3.

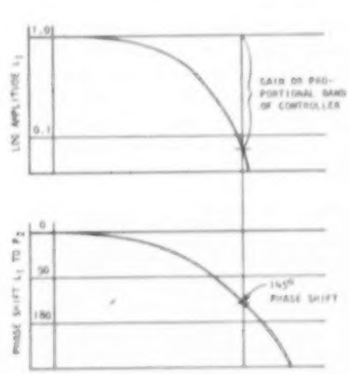


Fig. 4.

Fred Woods (Carbide & Carbon, South Charleston, W. Va.) makes a point.

have an analog computer. The hand manipulations of control functions beyond very simple servo systems get to be quite laborious, and when you consider all the different combinations of control modes and start to look at all kinds of control schemes, you get so bogged down in graphical manipulations that you quickly lose interest in the problem.

Alexander: The problem too, as pointed out by Dave, is such a complex problem, that you're forced to take approximations, and as someone said earlier, approximation is certainly better than nothing at all.

Buckley: I'd like to make the comment, Wayne, that just as in the past we've built up a backlog of control system design procedures based on practical experience in the plant, so, as a result of making many studies by modern feedback control techniques, we are developing new procedures. In many cases it isn't going to be necessary to make many calculations, but just to follow those procedures.

Aikman: The practical use of frequency response on the spot is, in a sense, self-liquidating. After you have done one or two, you get such an insight into dynamics, as to what is really going on inside the plant (and more than anybody else can tell you), that you soon find you don't really need to do much more at all. You get a semiapproximate engineer's feeling for it.

Dushkes: I would like to say that there are relatively few basic "chemical" processes, and if enough could be learned about their unsteady state behavior, it would be possible to prepare handbook procedures and formulae for the guidance of control engineers. A person relatively unskilled in the subject of dynamic analysis could then do a reasonably good job of instrumenting processes by referring to these results. This is the goal toward which we are working.

Alexander: You're saying right now that this type of information isn't available and hasn't been developed to a state of reduced usable formulas or tabular forms.

Buckley: Well, I think we're not far from having information which would be usable for probably 75 or possibly 90 per cent of typical plant control problems. There are four types of problems which constitute about 95 per cent of all process control problems. Those are temperature, pressure, flow, and liquid level. Now pressure, flow, and liquid level all come under the heading of acoustic problems in a strictly technical sense. The basic information necessary to solve them is already available in the acoustical literature *(1)* for people who know enough mathematics. The basic requirement is some knowledge of operational calculus and complex variable theory; these permit handling many differential equations by purely algebraic techniques. It won't be long before we have these problems reduced almost to handbook form. The temperature control problems, however, fit into a different group of problems involving heat exchangers and fractionating columns. The dynamics of heat and mass transfer are still difficult, but useful results are beginning to come out of the extensive research going on in these areas.

Alexander: Russ, I wonder if you would take up the subject of what further data we need for this.

Aikman: It depends on what type of data and what you want to do. You might say, in general, the concept of system design, if intelligently used, enables the control engineer to make the best use of limited data available. I am sure that the data available in published form on dynamics is very limited today. Nevertheless, a whole lot can be done with what there is if you know what the problem is. Defining the problem properly is the necessary thing. After that you can approach it.

In general, to design any control system on a rational basis, you need five different kinds of information:

1. You need to know the steady state parameters of the system. It is not always easy to get them. Even in fractionation, for example, you cannot get all you want to know out of the books.

2. You need to know about process dynamics, which we have talked about.

3. On the magnitude and the nature of the disturbances. As I said before, if there are no disturbances, you don't need any control.

4. You need to know the dynamic characteristic of the instruments (the hardware); if you talk nicely to the manufacturers you can usually get this.

5. And this may be the most difficult one—you need to define suitable operation criteria. In other words, you have to know what you want to make and how you are going to make it.

Buckley: I'd like to take one small issue with one thing Russ Aikman said. It is not entirely true that if you have no disturbances your plant will be entirely stable. When you have a feedback system describable by nonlinear differential equations, you often have, inherently, the possibility of an oscillator. Furthermore, this sometimes exists in practice. What this means is, that if the plant gets the slightest temporary upset which is not repeated, the plant itself can go into oscillation.

Woods: The point that Page just made brings out another point, and this is: assuming that you have a system you find would be oscillatory either in the design stage or in an existing plant, before you spend the time that it would take to make a dynamic analysis you might first determine whether the oscillation actually causes any difficulty. It is just possible that the oscillation could be tolerated with no detrimental effect to the product at all.

Boyd: I think what Russ said boils down to the simple fact that we need to get process control on a factual basis. That has been the whole problem of the industry. We have not been able to put performance quantitatively on paper. The result is that we get a man calling on us with a controller, which he says is "good"; it is "very good." And we are still in the hole.

Today, we are reaching a point where it is possible to get this information on paper, and in a way which can be easily utilized without having an advanced degree in mathematics.

Dushkes: Many people still regard controllers as set-point controllers. Generally speaking, set points are varied only during start-up and shutdown. The remainder of the time the controllers are regulating against load disturbances, the origin and nature of which we know very little about.

Draffen: I would like to ask Russ a nasty question. We are talking about the data we need. Knowing the dynamic response, can you tell what the

response is going to be in the same type of equipment of a different size, or with a different type of material running through it?

Aikman: Preferably, the data should be correlated, in a sufficiently fundamental way, to enable you to extrapolate to other material or operating conditions. Such data are difficult to get and it will be a long time before we have enough.

Draffen: In other words, we need correlated data.

Aikman: Otherwise, the best we can do at the moment is to get data from one or two further typical pieces of equipment, and do a little judicious extrapolating. That's what engineers are paid for anyway. You know, for example, that heat transfer rates are proportional to flow rate raised to the 0.6 power, and in a similar fashion

you can get other relationships—by using the back of an envelope you can make extrapolations on dynamics.

Draffen: We are talking about an extension of chemical engineering in-

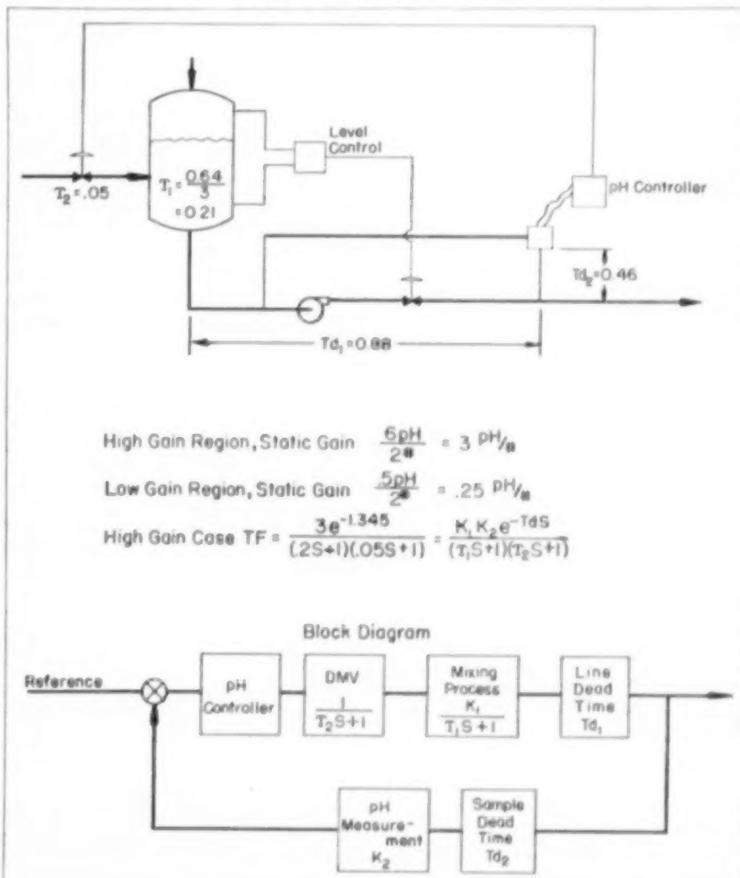
HOW NOT TO DESIGN A CONTROL SYSTEM

Woods: This has to do with a simple *p*H control (Figure 1), and I would put parentheses around "simple," because most of the time it doesn't work out that way. The material to be controlled enters the top of the tank. The reagent is introduced at a point below the liquid level. I have represented the lags with 0.2 min. being the time constant of the mixing tank, a dead time of 0.88 min., representing the line between the mixing tank and the point at which the sample is taken off and then another length of tubing for the sample itself for roughly 0.5 min. dead time. The process, as it was designed, turned out to be completely uncontrollable. The *p*H ranged from about 5 to 12 with a continual oscillatory output.

I believe the cause of the difficulty is fairly obvious since the sampling point was located so far away from the mixing point that it would appear to be almost impossible to sense the change in *p*H in time to take corrective action. However, the actual quantitative magnitude of the difficulty had to be measured in terms of the frequency response. With standard techniques, it was predicted that the throttling range necessary to produce stable control for this system was in the neighborhood of 3,000 per cent—plainly impractical as far as present-day controls are concerned. The obvious solution to the problem is to remove the dead time by taking a sample back at a point immediately following the mixing vessel. However, this does not eliminate all the problems in the system. The volume of the mixing tank in this instance is so small that the process has a terrifically high gain due to the *p*H characteristic of the material being controlled, and this is where the nature of so-called "systems design" would have produced the greatest benefit. In order to solve this problem completely, it was determined that the mixing tank should have been made larger in order to increase the time constant of this particular phase of the process and, at the same time, reduce the gain so that faster responding control could have been achieved. This might be thought of as downgrading the process equipment to some extent, but in this particular case it would have been absolutely necessary in order to make the system controllable at all and, therefore, represents a very positive step in the direction of systems design since it affects the sizing of the equipment as well as the application of the controls.

This illustration shows, without a doubt, how a piece of control equipment should *not* be installed! It was installed as a matter of expediency—recognizing that *p*H had to be controlled—but without taking into consideration any of the possible difficulties that might arise in bringing about this control. It is the type of system which would lend itself very easily to dynamic analysis ahead of time so that the actual controllability could have been predicted just as it has been predicted by this illustration. The changes which have been outlined to make this system completely controllable are in the process of being added at the present time.

Fig. 1. A simple pH control system.



A. R. Aikman (Schlumberger Well Surveying Corp.) suggests using the back of an envelope.

volving the unsteady state in addition to the steady state. I personally don't believe mathematics alone, using differential equations, will be the answer. It's going to take that plus empirical correlation, analog computers, and anything else that will work.

Dushkes: Relating to what Russ Aikman was just saying, I would like to point out the complicating factor that some chemical processes are very nonlinear. Such processes can be considered linear only for very small excursions about the operating conditions. If we deduce dynamic response from data taken in the plant at one set of operating conditions, the results may very well not be applicable at different operating conditions.

Draffen: Not having an analog computer, I am a firm believer in linearization. I would like to point out that, although our processes act nonlinear, a great deal can be told about their behavior by considering small deviations around the mean operating point, and though assuming linearity may result in 50 per cent error, the answer you get is better than no answer at all.

Boyd: Through trying to get better control we're going to stay in smaller excursions, and we're going to be in the more linear range of the processes.

Dushkes: The point I'm trying to make is that if you want to learn about a particular process, it is not sufficient merely to take some dynamic response measurements in the plant at the operating conditions. It is also necessary to gain an insight into the process and arrive at some approximate transfer functions which, when solved with the known operating conditions, will agree reasonably well with the response measurements already taken.

WHAT TO DO ABOUT PRESENT PLANTS

Alexander: Could we now pull out the crystal ball and look into the future as to dynamic studies of present plants and their payoff?

Woods: The things I think that you stand to gain the most of by working with existing plants and existing equipment are experience and knowledge. You can buy knowledge, but you can't buy experience for yourself. By the same token, it would be difficult to apply dynamic analysis techniques in process design without having had some experience in working with the technique on existing processes.

To my mind, the problem we face in this field is that a good many of the process engineers and the operating engineers don't even recognize that they have a problem, whether it is a specific control problem or something which involves operating efficiency of the unit. I think that this is an area in which dynamic analysis could be of tremendous assistance. If the operating engineer could be convinced that his process efficiency could be improved, even by a factor of ½ or 1 per cent, it might turn out to mean literally hundreds of thousands of dollars a year.

Further, I think that the same point of view follows in the design phase as well. Perhaps the design engineers are quite often satisfied with what they have now. It certainly behooves them to take another look at the situation, particularly with continuing increase in competition between companies, as to just how they can get a little more out of the processes that they are designing. We at Carbide are always building new installations of existing processes and this is an area from which we stand to gain a terrific amount of money.

To repeat, I feel that there is an element of complacency, both in the operating departments and in the design departments. In both instances, they are so close to the situation that they perhaps don't realize that improvements could be made and perhaps they wouldn't even like to *admit* that improvements could be made. I do think it is about time that they took a little more analytical view of the situation.

Draffen: Today, with present-day equipment, there is very definitely something to be gained by applying dynamic analysis in process design. The point I am trying to make is that, once the plant is built, the really big opportunity for making economic savings is gone.

Boyd: We had one such example recently which I think will illustrate the application of these techniques to an existing plant. We had a fractionating column installed which was definitely not meeting the situation as it should. The tower we set up should have been very stable. It had a flow controller on the feed, a flow controller on the heat on the bottom, and on the reflux. However, the tray efficiency was down to the order of 40 per cent.

By adding a rather high performance controller to the tower to readjust the reflux, we were able to stabilize the tower down further, because we were getting outside influences to air changes coming in through the reflux stream. The measure of tray efficiency after this curve, we found, had gone up to 48 per cent.

Aikman: I would like to add to what Jack and Dave said. The proper way to go about it, if you get the time and permission, is to start out in the design stage and do what calculations you can. When the plant is built, measure up and check with your calculations, then you have a springboard for the future.

Draffen: I feel that our present plants leave a lot to be desired in the way they control. Generally, they have to be started up manually, and the starting-up is often difficult. They are difficult to shut down, they are slow, and ponderous. As unexpected load changes occur, they get out of control. I think if we were really to go deeply into a study of the dynamics of processes and process equipment, we could design processes in which the equipment might be cheaper to build, and which would certainly be easier to operate and control.

Aikman: It seems to me that some of the troubles are just as much a function of the way the plant is operated as they are of the actual design of the plant itself. Jack mentioned, for example, unexpected, heavy load changes; this is probably due to some careless operator slamming a valve shut without thinking or something of that sort without planning the schedule.

Draffen: However, at the present time, if there are load changes that the control systems can't handle, you have to put controls on the load changes, and this means chasing the thing back and forth until you finally unload the plant. All that is extra complication, extra equipment, and expense.

Dushkes: I would like to point out that start-up and shutdown are not so often performed that there is economic justification for making them completely automatic. Furthermore, it is not possible to predict all the eventualities that may occur in start-up and shutdown (especially emergency shutdown) and so it is necessary that the operators take over at those times.

Woods: It's the unexpected load changes that Jack mentions that could easily come about. In fact, in the processes that I am familiar with, chemical plants are sometimes designed to operate at 100 per cent capacity. The first year they operate at 120 per cent capacity, the second year 140 per cent, and then whatever else they can wring out of them.

PROCESS CONTROL

The more closely the process variables can be controlled, the more likely it is that you can wring that last 5 or 10 per cent out of the plant.

HOW RESEARCH AND DEVELOPMENT WILL BE AFFECTED BY THE DYNAMIC ANALYSIS APPROACH

Alexander: You're touching on a subject that I've been wanting to discuss—what will be the effect, for example, of the process dynamics approach to control systems design on the type of research we are going to get on the development of processes? Will we expect anything different out of our chemical research laboratories to assist engineering better to design plants than what we get today on the present basis of static conditions?

Buckley: Well, the unsteady state point of view is inherently a more general point of view than the steady state point of view.

This means that process dynamics, or the study of unsteady state process behavior, probably will not develop as a new specialization in chemical engineering. Rather, as chemical engineering becomes more basic, the unsteady-state point of view will gradully replace the steady-state. The latter, in fact, will come to be recognized as a special case of the former.

Boyd: I think the other thing that will eventually come to light is the fact that the newer processes are going to be much more demanding on automatic controls, with the result that the controls are going to have to be considered in the laboratory as Page has mentioned. I know that I have heard recently of a process in which a 5° F. change is a 5 per cent change in conversion; and yet in the

(Continued on page 216)

SPRAY DRYER EXAMPLE

Aikman: This one is also a rather simple example (Figure 2)—a spray dryer in which the controlled quantity was the temperature in the outlet duct. This was originally controlled by manipulations of the steam-control valve to the air heater.

Initially, the raw material was allowed to drop from the head tank to the atomizer. Although the dryer—as a dryer—was well designed, as a control system it was unsatisfactory because poor temperature control frequently spoiled the product.

We wanted to know, though, how much was wrong with it, so we carried out a frequency response analysis by wiggling the control valve and observing the corresponding wiggles in output temperature. From the frequency response we analyzed the system in terms of time-constants. The system, in the control engineer's representation, now looks like this: (Figure 3) where each block represents a lag. The major disturbance entering the system is of flow rate of the raw material, and from Figure 3 it is obvious that this enters so late that the whole system is too slow to counteract it.

What we did after that is fairly obvious: we put the control valve on the raw material line from the head tank and got the temperature controller to manipulate it direct. The whole system was ten times faster and control was quite satisfactory.

Incidentally, we also got some interesting information, and we found that the sum of the time lags in the drum that we actually measured by frequency response was about 25 per cent less than the ratio of capacity to throughput of the drying drum itself. This indicated that although it apparently worked efficiently, there was some dead space at the top of the drum which wasn't doing much work, so we got it both ways, and we learned a lot about chemical engineering machinery and about controls, too.

Fig. 3. Block diagram of spray drier system.

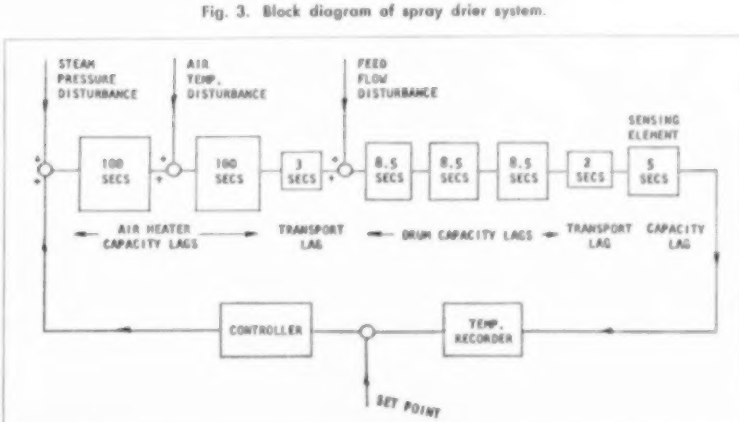
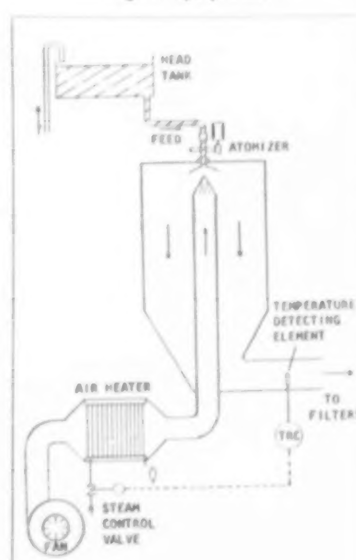


Fig. 2. Spray drier.



same plant, if it goes into commercial operation, a 1 per cent loss or inefficiency would be well over $100,000 a year. This is going to demand control in a way far beyond what they are now used to doing, and certainly the equipment is not going to be picked out of a catalog.

Aikman: I think that you can take another aspect of the research phase. I would like to point out that some work has been done, and is still being done, on the use of dynamic analysis to obtain plain, ordinary, basic chemical engineering information. An example of this might be the work done at Princeton University, in which they actually did use the frequency response technique, and this enabled them to measure axial diffusion coefficients in a packed column.

Draffen: As to what we might expect out of the research laboratory, I think you should include engineering research as well as chemical or scientific. I feel that when we start to develop new processes, the men who do it have a manual control psychology. They know when they get through with the development that the resulting plant has to run, and they think of running it themselves. As a result, there aren't too many of our present-day plants that couldn't be controlled manually—if they decided that they were going to do it no matter how much it cost or how many men it took. However, if we release ourselves from these restraints and let our imaginations run wild, I don't know that there is any way of predicting what might come out of it, but in the future I think we will be running processes that we couldn't even begin to control manually.

FUTURE TECHNOLOGIC DEVELOPMENTS AND THEIR EFFECT ON SYSTEMS DESIGN

Alexander: For our last subject—how about future technological developments and their impact on systems design? Jack, do you want to talk about that?

Draffen: I am not so sure that some of the things that are likely to come about in the future are going to be solely or entirely due to automatic control. There's going to be a general advance in chemical engineering science which is made possible by our proved ability to control process equipment. We might expect to see smaller and faster reacting equipment which can be made to control better, but which also needs better control for its operation.

Aikman: My crystal ball indicates that there is research going on at the moment which will result in some real technological break-throughs in the near future. Thinking in terms of instruments, reliable on-stream analysis instruments are being developed which will enable us to make measurements which are now impossible except in the research laboratory. One can now clearly foresee the application of special-purpose computers of such reliability that they can be used to compute plant balances continuously as an operational and managerial guide. Developments such as these are sure to have a profound effect on system designs of the future.

On the other hand, we now have many tools. We should better know how to apply them. We don't have too much data, but that is coming. We have, I think, more instruments than we are presently prepared to use.

What is lacking is the general understanding, and the proper definition of the problem, in other words, "attitude." It is a psychological and not a technical problem, which makes it ten times more difficult.

Boyd: What really would throw progress into an upheaval would be for management to get preliminarily convinced that they should have plants run entirely automatically. If such is done, it probably would not come from the supplier side, from those who would not have a measure of the problem as far as the process itself was concerned.

I think we are going to find that control evolution is going to come from the users of the equipment because they are the ones who will have the first chance of appreciation of the actual control problems.

Alexander: Does any one have another thought?

Buckley: I'd like to make the final comment that a good system operation depends not only on good system design, but on the way the plant is run. We have now already passed the point, in newer plants, where maintenance employees outnumber production employees. Also, there has been a sharp upward swing in the amount of technical knowledge required of maintenance mechanics, particularly in instrument work. In the near future—in fact, already to some extent—this is a limiting factor in the design and installation of advanced types of control systems. We may have to face the fact that we will be using technicians or people with a completely different background from our present instrument mechanics if we're going to use this very fancy equipment.

WHAT THE CHEMICAL ENGINEERING PROFESSION SHOULD DO

Alexander: A last question: What should we do on academic and professional levels?

Buckley: Today we have a rather double-barrelled problem in trying to apply automatic control. First, in industry we don't have enough people trained in this kind of work, and second, there does not exist a very strong activity at the academic level. Now from industry's point of view, it may be necessary to consider one or more of three short-term ways of getting such people. One way would be to give process engineers some training in feedback control techniques and instrumentation. Another approach would be to give instrument engineers some training in feedback control techniques and process engineering, and finally we could take servoengineers (who are usually electrical or mechanical) and teach them process engineering. Now we'll turn to what the profession should do. First, we should encourage process engineers and instrument application engineers, many of whom are originally chemical engineers, to take an interest in these modern techniques of control system design.

We should encourage universities and technical schools to include process control as an important part of chemical engineering curricula.

We should establish liaison with the A.I.E.E. and the A.S.M.E., since these organizations are already active in the area of process control.

These policies should be implemented by symposia on process control, publishing of papers on process control in *Chemical Engineering Progress* and *A.I.Ch.E. Journal*, and by recommending training and educational programs both to industry and schools.

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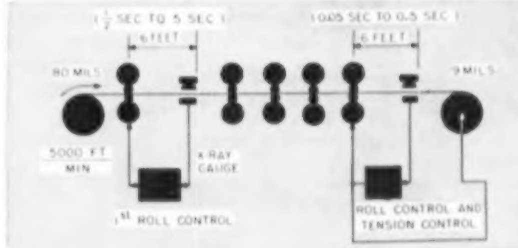

Fig. 1. Cold rolling mill.

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The author proposes a novel method of obtaining high accuracy in a process control loop by using a minor feedback loop around the controller to prevent dead-time-excited oscillations. The step response of this minor feedback loop has the characteristics of a pulse generator, and therefore is similar to a phase lead network. The minor feedback loop generates the difference between the system output which would exist without the dead time and the system output which actually exists with the dead time. When this difference is introduced in negative feedback to the input of the controller, it allows the permissible gain of the controller to be adjusted to a very high value. This minor loop stabilizes the system and permits the proportional band to be very small. It reduces the time to recover from an upset to approximately the value of the system dead time. It is theoretically impossible to reduce the correction time further.

CLOSER CONTROL OF LOOPS WITH DEAD TIME

A wide variety of servomechanisms and process controls have transfer functions which include a pure transportation lag or flow time. This is called a "dead time." It is difficult to stabilize loops containing this element with the conventional proportional plus rate plus reset controllers. For a simple proportional controller, a rule of thumb for the permissible gain is the ratio of the largest system time-constant to the dead time. If the largest system time-constant is relatively small, and the dead time is significant, then it is difficult to obtain high accuracy by virtue of a high loop gain.

COLD ROLLING MILL EXAMPLE

One type of dead-time system is the cold rolling mill shown in Figure 1. Steel plate which is 80 mils in thickness is rolled down to 9 mils thickness through 5 rolls. The first roll is designed to smooth out the variations in thickness in the incoming sheet. An x-ray thickness gauge following the roll measures the sheet thickness and a controller adjusts the pressure on the rolls to attempt to keep the thickness constant. The spacing between the rolls and the gauge which measures the effect of pressure changes is 6 ft. This represents a time delay of between ½ sec. and 5 sec., depending upon the speed of the sheet. Changes in pressure on the first roll are propagated slowly as thickness changes through the entire system, and therefore the first roll is used primarily as a regulator, and not as a fine control. In order to stabilize such a long dead time, it is conventional to use a periodically sampled system for the first roll control. The method proposed in this paper would be applicable here (*2, 3*).

In Figure 1 the sheet continues through three more rolls until it arrives at the final roll. After it passes through the final roll, another x-ray thickness gauge measures the final thickness. This value should be held to close tolerances. There are two methods available for using the measured thickness to correct for thickness errors: if the tension on the take-up roll is increased, the thickness will diminish; or, if the pressure on the final rolls is increased, the thickness will diminish. In either case, the dead time in the system is that represented by the 6-ft. distance between the final rolls and the x-ray gauge, which is equivalent to 0.05 to 0.5 sec., depending upon the speed of the sheet.

CATALYTIC CRACKER EXAMPLE

A catalytic cracker to produce gasoline from gas oil is shown in Figure 2. The rate of flow of oil is controlled by the flow controller preceding the heat exchanger. This is followed by a furnace which is regulated by a temperature controller from the output oil temperature. The oil charge enters the bottom of the reactor after having been mixed with fresh catalyst from the catalyst regenerator. The cracked products pass out at the top of the reactor to two fractionating towers from which gasoline, heavy oil, and other fractions are obtained. The primary control on the reactor is a temperature controller which measures reactor temperature and controls the flow of fresh catalyst. In addition, the flow of catalyst into the spent catalyst stripper is controlled by a differential pressure controller which measures the pressure drop through the reactor. The pressure through the spent catalyst stripper controls the flow of spent catalyst back to the catalyst regenerator (*1*).

To make this system completely automatic, there should be an over-all feedback loop from one or more separated products in the second fractionator, back to the reactor temperature controller. This loop might control the reset rate on the fresh catalyst flow. An over-all feedback loop of this sort would encompass the flow time of the reactor and the two fractionators and of the piping between them. It would be difficult to have a very close control or high gain in this loop without giving due consideration to these excessive flow times.

Process Transient

The amount of dead time in any process can be determined from the process step response, when operated with manual control. If the control valve is given a small incremental change, the recorder controller will plot an output transient curve somewhat like that in Figure 3. This curve can be analyzed by first drawing the

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tangent to the curve at the inflection point where the slope is steepest.

Call T_a the time encompassed by the tangent to the curve between the initial and the final values. The intersection of the curve tangent and the initial value of the curve occurs at time $T_b + T_d$ after the incremental change, where T_d is the dead time. At this time, the value of the actual curve is a. The line b through $g = \epsilon a$ at time $T_d + T_b$ and parallel to the curve tangent is T_b in advance of the curve tangent in Figure 3. (Epsilon [ϵ] denotes the base of Napierian logarithms.) The dead time T_d is the time from the instant of the initial incremental step change to the intersection of the line b with the horizontal axis.

The two time constants of the system can also be determined from Figure 3. Let the factored values be T_1 and T_2, where T_2 is the smaller, and let

$$x = T_2/T_1. \qquad (1)$$

In Figure 3, divide T_a into the two times T_f and T_c respectively before and after the tangency and inflection point.

Oldenbourg and Sartorius (5) have shown that

$$T_c = T_1 + T_2 = (1+x)T_1 \qquad (2)$$

$$T_a = \left(\frac{1}{x}\right)^{\left(\frac{x}{1-x}\right)} T_1 \qquad (3)$$

$$T_c/T_a = (1+x)x^{\left(\frac{x}{1-x}\right)} \qquad (4)$$

$$f(t) = 1 - \frac{1}{1-x}\epsilon^{-t/T_1} + \frac{x}{1-x}\epsilon^{-t/T_2} \qquad (5)$$

To calculate values, it is convenient to use the following procedure: g can be calculated approximately as

$$g \cong a\left[\epsilon + \frac{0.53}{1+(150a)^{-8}}\right] \qquad (6)$$

T_b can be measured graphically or calculated as

$$T_b = gT_a \qquad (7)$$

The smallest time constant T_2 lies between T_b and $(T_b + T_f)$ in value. It is approximately

$$T_2 = T_b[1 + 10a + (\epsilon - 1)(30a)^2] \qquad (8)$$

When a is more than 0.005, the time constant is approximately

$$T_2 = (T_b + T_f)\left(1 - 200(0.032-a)\left[1 + \left(0.086 + \frac{0.0015}{0.032-a}\right)^{-1}\right]^{-1}\right) \qquad (9)$$

The largest time constant T_1 is

$$T_1 = T_c - T_2 \qquad (10)$$

The inflection point is sometimes not well defined on the graph. To check T_1 and T_2, substitute them in Equations (1) and (3) and compare the calculated T_a with the measured value.

The transfer function of a process with this open loop transient response is given by

$$G(j\omega) = \frac{K\epsilon^{-j\omega T_d}}{(1+j\omega T_1)(1+j\omega T_2)} \qquad (11)$$

$$G(s) = \frac{K\epsilon^{-sT_d}}{(1+sT_1)(1+sT_2)} \qquad (12)$$

The first of these is expressed as the ratio of the sinusoidal output vector of the process divided by the sinusoidal input vector. The second equation above uses the LaPlace transform notation common in control literature. The constant K is the ratio of the total change of the output variable divided by the incremental change of the control valve.

Block Diagram

The block diagram for a conventional process control system is shown in Figure 4. The input is the fixed set point θ_i from which is subtracted a signal proportional to the measured value of the output controlled variable θ_o. The controller amplifies this error and delivers a signal to a valve in the system. The transfer function of the valve and the system has been here grouped into two functions of frequency G_1 and G_2 and two dead times T_1 and T_2. The controller G has proportional plus rate plus reset control. The dynamic functions G_1 and G_2 have time constants which are of the same order of magnitude as the dead times T_1 and T_2. Unfortunately, there is a maximum reset rate for this system as shown which cannot be exceeded without stability difficulties.

Proposed Method

The first step in designing a system which can have either a much narrower proportional band or a much faster reset rate is to draw the block diagram of the system as it exists, except for the dead times. This block diagram is shown in Figure 5a. With this block diagram as a basis for determining the controller settings, G_3, the reset rate, proportional band, and rate adjustments are calculated to give the maximum speed of recovery from a disturbance, and the closest possible control of the output variable θ_o, within the limitation of stability. The fictitious process which was used here can be called the minimum-phase analog of the actual process, and the controller setting G_3 will be called the optimum minimum-phase control.

The next step in the system design is to convert a statement of the optimum mode of control into a diagram showing the physical arrangement of the components. Figure 5*b* is a statement of the optimum mode of action desired of this controller. It starts with the optimum minimum-phase loop shown in Figure 5*a*. The output of this loop goes through the unalterable system dead time. This is a statement that the best that can possibly be done is to bring the output to equal the set point in a time equal to the dead time of the system, when the set-point is suddenly changed. In addition, compensation for the unknown system disturbances is shown introduced into the feedback loop. The controller is not able to detect system disturbances θ_d instantly, but must wait until the disturbance actually arrives at the system output and changes the value of the controlled variable. For this reason, the disturbance θ_d has been delayed by the dead time T_2 before being introduced into the optimum minimum-phase loop.

A third statement is contained in Figure 5*b*. It says that one can actually measure only the output variable and therefore one must operate with a negative feedback loop from this point. The negative feedback loop has been introduced around the system as a whole and a compensating positive feedback loop has also been introduced so that the optimum control which was postulated will not be disturbed. This, of course, is not the way the system will be built, but is only a statement of the mode of action desired.

By means of block diagram substitutions, the constructional arrangement will now be derived. The outside negative feedback loop in Figure 5b will be left unaltered. The positive feedback loop will be "shrunk" in size until it coincides with the inner minor feedback loop, and then these will be combined. The first step is shown in Figure 5c. First, G_1 and G_2 were moved after the branch point in Figure 5b so that they could be combined with the dead times in the manner in which they actually existed in the system as shown in Figure 4. This resulted in G_1 and G_2 also appearing in the inside minor feedback loop. Next, the positive feedback loop encompassing the entire system was taken off from ahead of the disturbance θ_d instead of from the output θ_o. This resulted in the minor loop with the transference $FG_2\epsilon^{-sT_2}$ shown in Figure 5c. The third step is to move the branch point for this loop from the output of the T_1 dead time to the input of the T_1 dead time. This results in a minor feedback loop transference of $FG_1G_2\epsilon^{-s(T_1+T_2)}$. Combining the two minor feedback loops results in the final system design shown in Figure 6.

PROCESS CONTROL

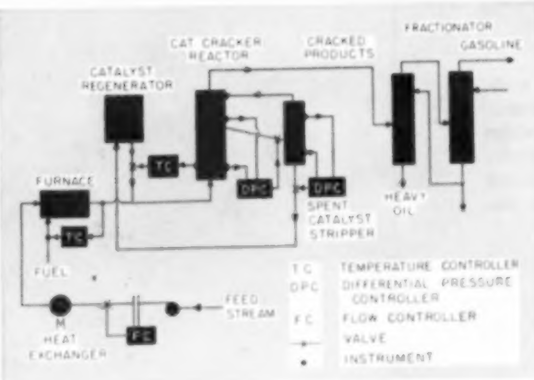

Fig. 2. Catalytic cracker.

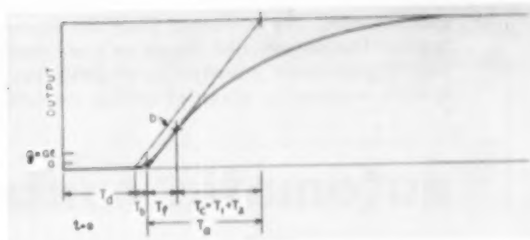

Fig. 3. Output transient curve of recorder controller.

The final system deviates from the optimum minimum-phase control shown in Figure 5*a* through the addition of a single feedback loop from the output of the controller (before the control valve) back to the input of the controller at the point where the error between the set-point and the measured variable is amplified. This minor feedback loop has for its main characteristic the transfer function $1 - \epsilon^{-s(T_1+T_2)}$. If the controller should deliver a step function, this step function would appear in the output of the minor feedback loop only for the time $T_1 + T_2$, and then would disappear, there being no further signal passed. The minor feedback loop therefore is a pulse generator which passes only high frequencies and does not pass any low frequencies, and does not alter in any manner the precision of the system. It makes possible the settings of the controller G_3 exactly equal to the optimum minimum-phase settings, even though the controller is operating on the actual system including long dead times. Also included in the minor high frequency feedback loop is the transfer function FG_1G_2, which is a miniature model of the minimum-phase or time-constant parts of the system (*4*).

Another way of describing this minor stabilizing loop is that it is the difference between two models of the actual process. One model is a minimum-phase model including only the time constants, and the other model is the long dead-time model including all the parts of the process. The difference between these two models provides the appropriate stabilizing function for the controller.

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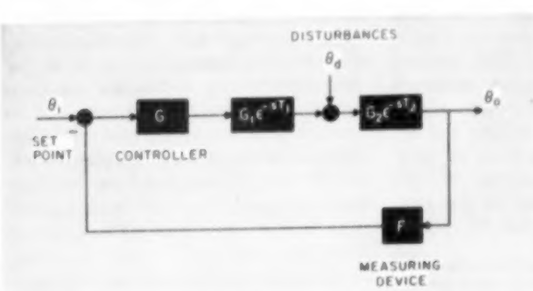

Fig. 4. Block diagram of conventional process control system.

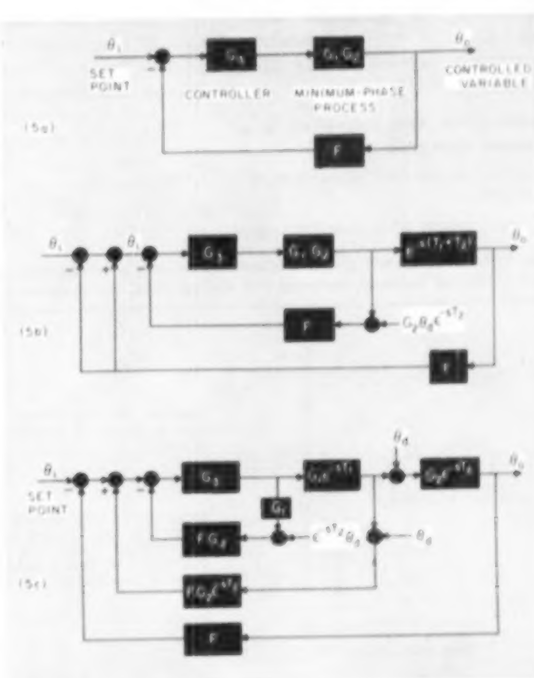

Fig. 5. Step design of control system.

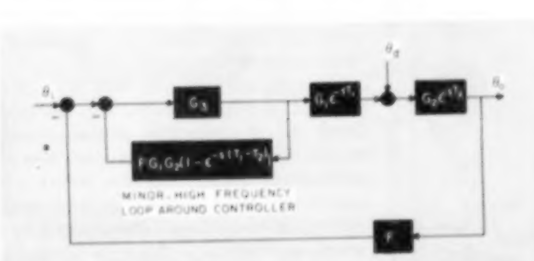

Fig. 6. Final system design.

In the accompanying article sampling and control techniques, which are necessary with the use of such instruments as mass spectrometers and infrared and ultraviolet spectrometers, are evaluated from the control dynamics aspect. The authors also report on some results obtained from a preliminary investigation of distillation column frequency response by means of analog simulation.

automatic control in CONTINUOUS DISTILLATION

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The present article is a continuation of the study of the automatic control of a continuous distillation column by methods of analog computer simulation previously reported (*2, 4, 5*). The mathematical model of a distillation column used here has been fully described in the previous papers. However, for completeness the schematic and block diagrams of the column are presented again here as Figure 1 and Figure 2, respectively. This is a five-plate column separating a binary mixture with a constant relative volatility. The frequency response part of this paper is the computer simulation equivalent of the experimental study previously carried out by Hoyt and Stanton (*1*).

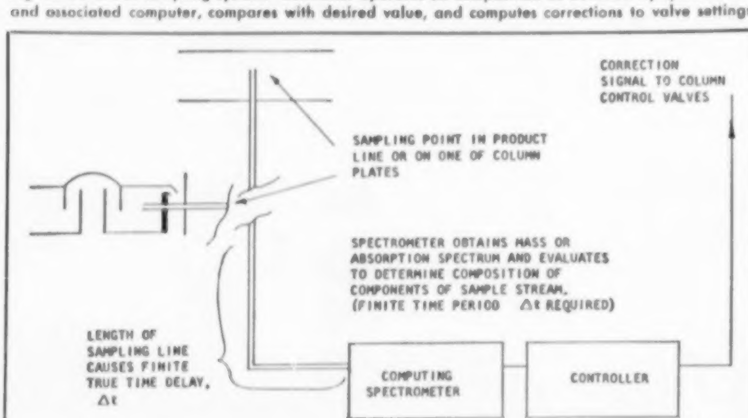
Intermittent Sampling—Effect Upon Column Controllability

SIMULATION OF SPECTROMETER-TYPE SAMPLER

As a model of a sampling system to be duplicated by computer simulation techniques use is made of that described by Figures 3 and 4. The assumption here is that a sample is taken at the specified sampling point which may be in the product line or on one of the column plates. There is a finite period of time which is required to traverse the sample line after which the sample will be ready for evaluation by the spectrometer. The next supposition is that the spectrometer is equipped with a computer which will enable it to produce an output representative of the actual composition of the sample stream rather than to give merely its per cent absorption at various frequencies. This process of obtaining the absorption spectrum and of converting it to signals representative of actual composition will require another definite period of time. Therefore, the composition of the stream will be available to the controller for determination of output error and for the computation of the required control correction only after a period of time which is the sum of the two periods just mentioned.

In addition, because the spectrometer or its associated computer can operate only upon one sample at a time, the controller must make use of the result from each discrete sample as a constant for that period of time necessary for the spectrometer and its associated computer to complete their operation. Figure 5 diagrams this situation. For purposes of completeness it will be assumed that the periods of time entailed in sample-line true-time lag and in spectrometer plus computer operation are the same. This is done for convenience only and is not an absolutely necessary assumption. It is necessary to know only the total-time delay involved and the sampling interval or rate of sample-taking which is used.

Fig. 3. Details of sampling system. Controller operates on composition as detected by spectrometer and associated computer, compares with desired value, and computes corrections to valve settings.



RESULTS

Stepwise variations in feed composition of ± 0.12 mole fraction more volatile component were used as forcing functions for a series of computations which was carried out for a wide range of controller constants and for a correspondingly wide range of sampling-delay times. The results of these computations were plotted on the same type of graph as had been developed in previous reports from this study (*2, 4, 5*). This is considered to be the most compact and direct method of illustrating the effect of sampling delay and intermittent sampling rate upon the column control dynamics. Figures 6 through 17 show the results of the calculations plotted in this manner.

In order to show further the effects of an increasing sampling interval, the maximum proportional constant from each of the above-mentioned graphs which still gives a stable response is plotted against the corresponding sampling interval for top plate sampling in Figure 18, and for intermediate plate sampling in Figure 19. It can be seen from these plots that the permissible value of the proportional constant falls rapidly until a sampling interval of about one-half the basic-column time constant, τ_2, or three seconds is reached. After this point the rate of decrease is less as sampling interval increases. However, the permissible value of the proportional constant is now much smaller.

This same point has been previously brought out in a study of other systems. For example, Truxall (*3*) reports that the maximum sampling interval should be less than one-half the system time constant when expressed in the same units of time. Thus the maximum sampling interval in our distillation column should be three seconds or less since most time lags in the system are six seconds. This is verified by Figures 18 and 19.

Frequency Response of a Distillation Column

INVESTIGATION OF PROBLEM

Although all the previously reported work of this investigation (*2, 4, 5*) has been confined to the transient response of the column, some preliminary aspects of the other commonly used type of response testing, frequency response, were also carried out on the analog computer by using the same computer setup as before but by using

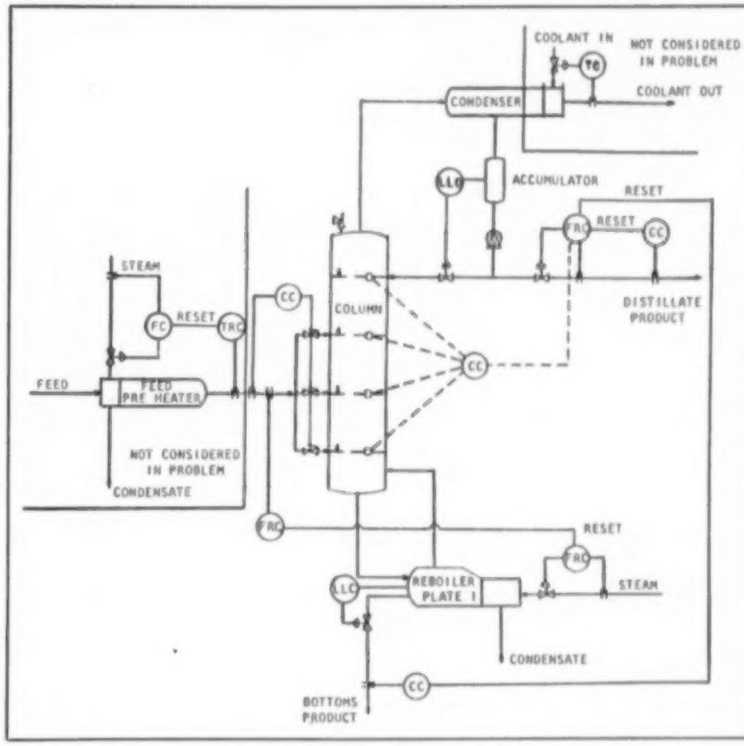
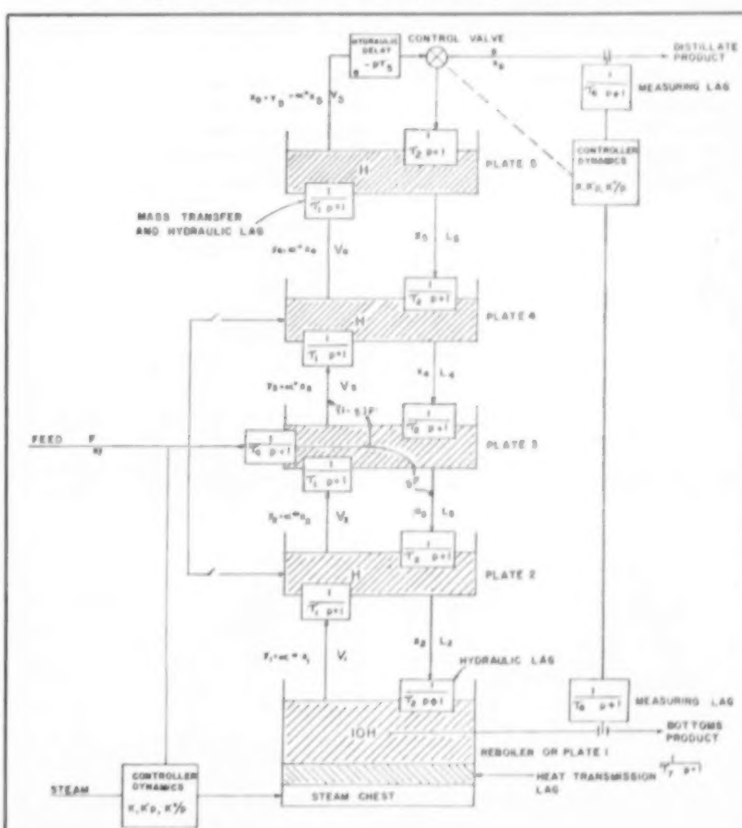


Fig. 1. Diagrammatical representation of distillation column automatic control.

Fig. 2. Distillation column automatic control dynamic relations.



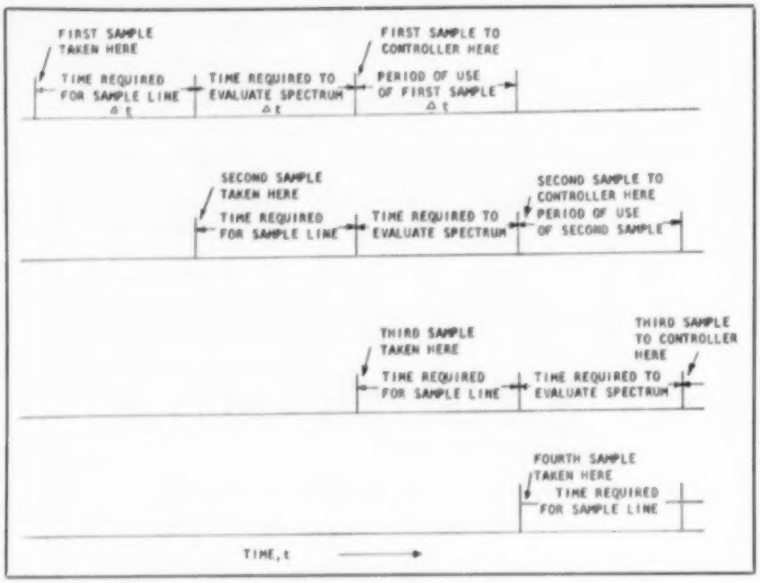


Fig. 4. Time relationship of events in operation of intermittent sampling model.

a sinusoidal variation of feed composition rather than a stepwise variation of feed composition as a forcing function. These tests are now reported here.

Because of the decidedly different response of the column to a composition variation in a constant-temperature feed compared to its response to the same composition change in a constant-quality feed (*5*), both types of feed were investigated.

For these tests the controller was disconnected completely from the column; that is, the tests were made on the open-loop system. A sinusoidal variation in composition of ± 0.12 mole fraction of the more volatile component at a widely varying set of frequencies was imposed upon the feed stream. The resulting variation of the composition of the liquid on each of the various plates of the column was measured. The ratio of the magnitude of the composition variation as measured on the plate to the imposed variation in the feed stream is termed the magnitude ratio and is one of the terms vital to a frequency response. The other important term is the phase shift or the number of degrees of arc by which the sine wave from the plate being sampled lags that of the imposed feed variation. Both terms are usually plotted vs. the imposed frequency in what is commonly termed a Bode diagram (*3*).

Figures 20 through 27 show these resulting log-magnitude ratio and phase-shift vs. frequency plots for each of the column plates for the case of a constant-temperature feed and the log-magnitude ratio vs. frequency plots for the upper three plates for the case of a constant quality feed.

If a feed which is varying in composition is maintained at a constant temperature, its quality or the ratio of vapor to saturated liquid will vary. This will then result in changing the relative liquid- and vapor-flow rates in the enriching and stripping sections of the column as the feed composition changes. If, however, as the feed composition varies, the temperature is allowed to vary also so that the quality of the feed remains constant, the column stream flow rates will remain constant during the composition upset. This is referred to as a constant-quality feed.

RESULTS

The readers' attention is invited to several points which are immediately apparent in studying these graphs. They are:

1. The striking effect of the constant-tem-

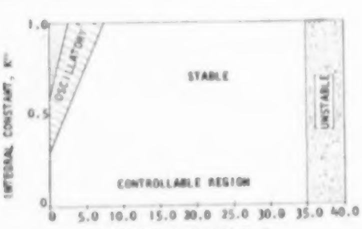


Fig. 6. Relationship of controller constants for top plate sampling. No sampling delay.

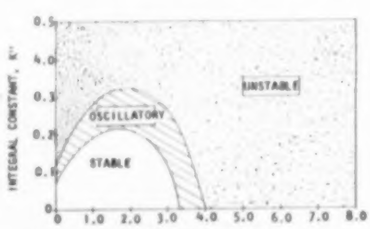


Fig. 7. Relationship of controller constants for top plate sampling. Sampling interval Δt = one sec.

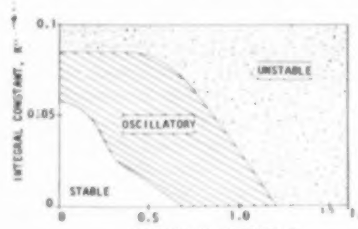


Fig. 8. Relationship of controller constants for top plate sampling. Sampling interval Δt = five sec.

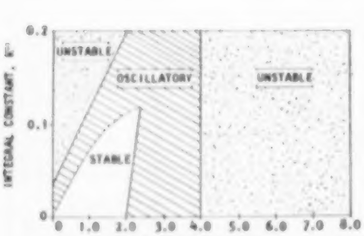


Fig. 12. Relationship of controller constants for intermediate plate sampling. No sampling delay.

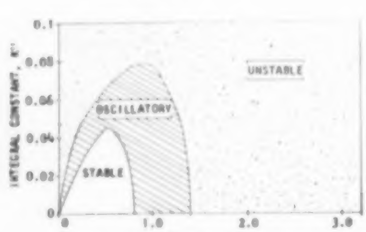


Fig. 13. Relationship of controller constants for intermediate plate sampling. Sampling interval Δt = one sec.

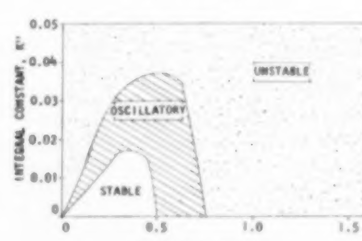


Fig. 14. Relationship of controller constants for intermediate plate sampling. Sampling interval Δt = five sec.

perature feed on the frequency response as compared to the constant-quality feed.

2. The basic underlying similarity of the two plots for any particular plate when the asymptotic lines are drawn on the constant-temperature diagram.

3. The plots of each of the column plates other than the top plate do not follow theory for the required slope of the asymptotes; that is, the asymptotic line does not have a slope of one, for example, it does not decrease one decade in magnitude per decade increase in frequency prior to the so-called "break point." Also, it does not have a slope of two to the right of the break point (3).

4. The response of each of the plates of the column is different from each of the others.

While the corresponding curves for both phase shift or phase lag and magnitude are presented here, several factors should be kept in mind in evaluating them. These are

1. The large values of phase lag are due to the many time delays involved in a distillation column such as tray hydraulics, condenser delay, sampling lags, and so forth. In addition, these values will increase greatly as more and larger trays are considered to be included in the column.

2. However, the control loop of the column as normally considered does not include the feed point. The control loop normally includes only the sampling device, the reflux valve, the controller, and that part of the column between the sampling point and the reflux valve. Thus, the really important fact we need to know is the magnitude and frequency of the sinusoidal variation at the sampling point which is caused by a given feed variation. The phase lag between the feed point and the sampling point is therefore unimportant or at best of relatively minor importance in the normal column-control scheme.

PROCESS CONTROL

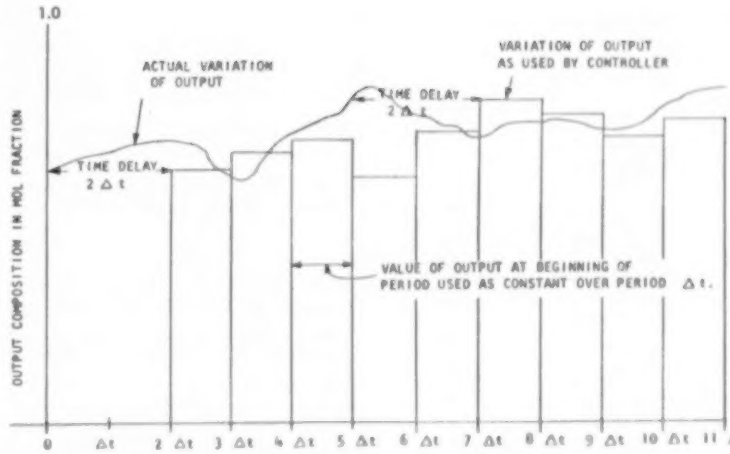


Fig. 5. Comparison of real output of process and that actually used by the cont

3. On the other hand, if one wished to originate a control scheme which involved sampling the feed and then making the necessary adjustments to the column to anticipate the effect of feed variations, the phase shift would be of vital importance in evaluating how long one should wait after detecting an upset before one adjusted the reflux valve.

4. In addition, if one wished to evaluate the effect of other types of upsets than sine waves upon the column and if one wished to do this by a Fourier series method rather than by use of an analog computer, the phase-shift data again would be necessary.

DISCUSSION OF RESULTS

Table 1 lists the response equations for each of the column plates as derived from the asymptotes of the plots of Figures 20 through 27. In each case these seem to indicate a Type 1 system with a single first-order time constant. The time constant of the system for most of the plates is seen to about 6 sec. This is probably the result of the first-order time constant of 6 sec. which is assumed for the sampling mechanism. The fact that these equa-

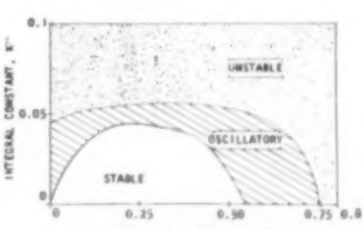


Fig. 9. Relationship of controller constants for top plate sampling. Sampling interval Δt = ten sec.

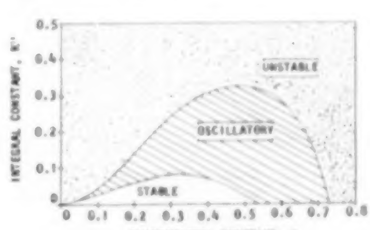


Fig. 10. Relationship of controller constants for top plate sampling. Sampling interval Δt = twenty sec.

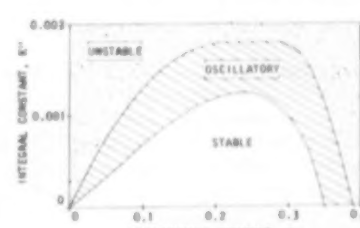


Fig. 11. Relationship of controller constants for top plate sampling. Sampling interval Δt = sixty sec.

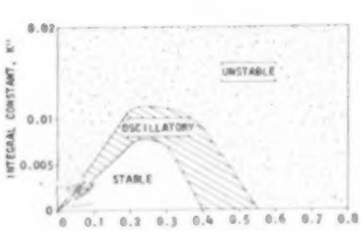


Fig. 15. Relationship of controller constants for intermediate plate sampling. Sampling interval Δt = ten sec.

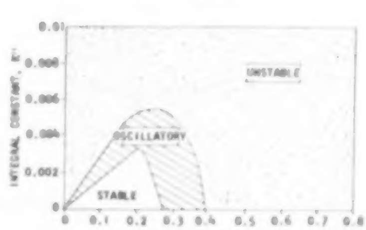


Fig. 16. Relationship of controller constants for intermediate plate sampling. Sampling interval Δt = twenty sec.

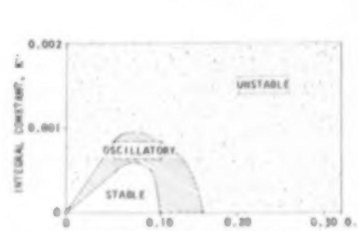


Fig. 17. Relationship of controller constants for intermediate plate sampling. Sampling interval Δt = sixty sec.

Table 1.—Apparent Transfer Functions of Plates of a Continuous Distillation Column

(Derivation from the Asymptotes of the Bode Diagram)

Plate	Derived Transfer Function
1	$\frac{x_1}{x_f} = \left[\frac{K_1}{s(s\tau_a + 1)}\right]^{\nu_1}$
where	$K_1 = 0.0355$, $\tau_a = 19.2$ sec., $\nu_1 = 0.76$
2	$\frac{x_2}{x_f} = \left[\frac{K_2}{s(s\tau_b + 1)}\right]^{\nu_2}$
where	$K_2 = 0.0397$, $\tau_b = 6.0$ sec. or 0.1 min., $\nu_2 = 0.63$
3	$\frac{x_3}{x_f} = \left[\frac{K_3}{s(s\tau_c + 1)}\right]^{\nu_3}$
where	$K_3 = 0.1$, $\tau_c = 6.0$ sec. or 0.1 min., $\nu_3 = 0.64$
4	$\frac{x_4}{x_f} = \left[\frac{K_4}{s(s\tau_d + 1)}\right]^{\nu_4}$
where	$K_4 = 0.0538$, $\tau_d = 6.0$ sec. or 0.1 min., $\nu_4 = 0.82$
5	$\frac{x_5}{x_f} = \left[\frac{K_5}{s(s\tau_e + 1)}\right]^{\nu_5}$
where	$K = 0.0126$, $\tau_e = 6$ sec. or 0.1 min., $\nu_5 = 1.0$

tions are not the true equations of the system is evident from an inspection of the graphs for the constant temperature condition where the effect of vapor and liquid flow variations is imposed upon the composition variations which are seen to be present alone in the constant feed quality case. In the constant-quality case, that is, composition variation alone, the derived equations would probably suffice.

The interaction of the column plates is evidenced by three factors apparent in the graphs: (1) the exponential terms in the intermediate and feed plate equations, (2) the apparent time constant of the still pot or plate 1 is seemingly unrelated to any of the column time constants which are given along with the other column parameters in Table 2, and (3) the effect of the vapor- and liquid-flow variations introduced by the variation of q as composition varies.

A major cause of the large hump on the constant-temperature curves, particularly that for the top plate is due to the fact that a time-delay period of

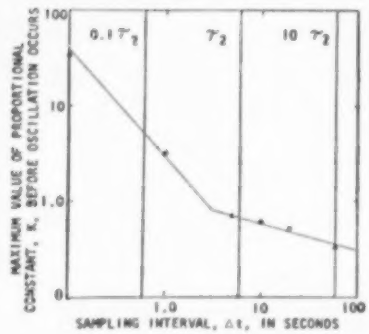


Fig. 18. Effect of sampling interval on range of controller constants for top plate sampling.

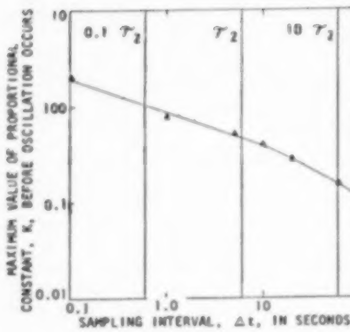


Fig. 19. Effect of sampling interval on range of controller constants for intermediate plate sampling.

one minute for the condenser allows a sinusoidal variation in flow rate with a period which is one minute or any submultiple of a minute to reinforce itself and thus greatly increase its effect upon the column. Since this is a flow rather than a composition phenomenon alone, these humps are not present for a feed with a constant quality. Figure 28 diagrams each of the factors given in Table 1 and shows the location of the imposed frequency with a period of one minute.

The results reported here, however, constitute only a part of the total work which would be necessary to specify the complete frequency response of a distillation column. Still lacking at this point is a similar study of the response to feed rate changes and to a variation in steam flow to the reboiler. This latter is necessary to define the effect of the still pot heat transfer lag, τ_7. Due to this lack of complete data a "black box" approach to the analysis of column behavior, as is evidenced by Table 1, is necessary.

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Table 2.—Column Parameters

H	Holdup	2.33 lb. moles/plate 23.3 lb. moles in still pot
F	Feed rate	200 lb. moles/hr. initially 3.33 lb. moles/min. initially
V_1	Boilup rate	400 lb. moles/hr. 6.67 lb. mole/min.
q	Feed quality	0.50 initially, varies between 0 and 1.0
x_f	Feed composition	0.50 initially, varies ± 0.12
$L_{o/D}$	Reflux ratio	4/1 initially for x_f of 0.50
τ_1	Column vapor-flow lag	negligible
τ_2	Column liquid-flow lag	0.1 min.
τ_5	Feed vapor-flow lag	negligible
τ_6	Feed liquid-flow lag	0.1 min.
τ_7	Heat transfer lag	2.0 min.
τ_8	Condenser true-time delay	1.0 min.
τ_9	Sampler mixing lag	0.1 min.
	Controller Parameters	
K	Proportional constant	Values as given in Figures 6-19. Units: $\frac{\text{moles/sec. of distillate}}{\text{unit mole fraction error in composition}}$
K''	Integral constant	Values as given in Figures 6-17. Units: $\frac{\text{moles/sec. of distillate}}{\text{unit mole fraction error in composition} \times \text{sec.}}$

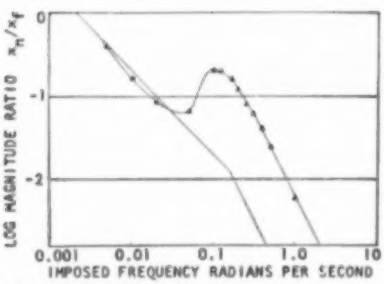

Fig. 20. Frequency response, top plate, constant temperature feed.

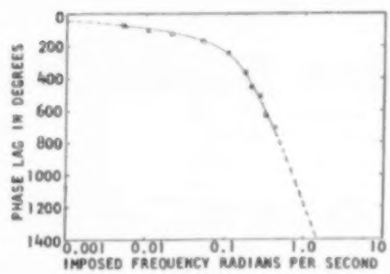

Fig. 20a. Frequency response, top plate, constant temperature feed.

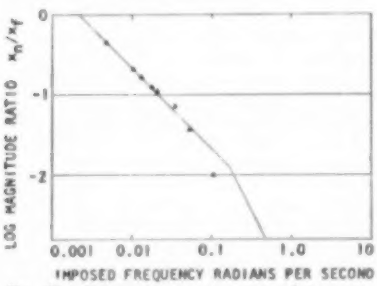

Fig. 21. Frequency response, top plate, constant quality feed.

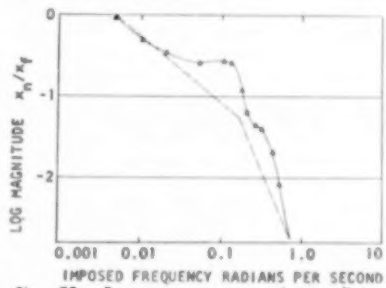

Fig. 22. Frequency response, intermediate plate—enriching section, constant temp. feed.

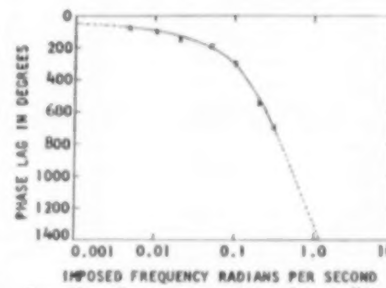

Fig. 22a. Frequency response, intermediate plate—enriching section, constant temp. feed.

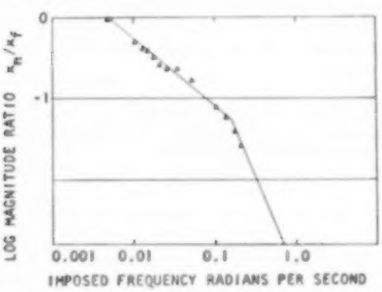

Fig. 23. Frequency response, intermediate plate—enriching section, constant quality feed.

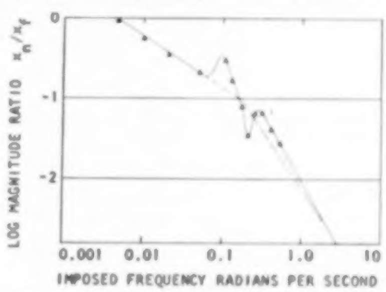

Fig. 24. Frequency response, feed plate, constant temperature feed.

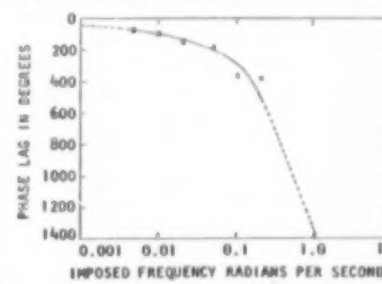

Fig. 24a. Frequency response, feed plate, constant temperature feed.

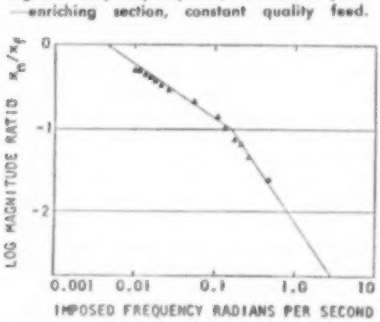

Fig. 25. Frequency response, feed plate, constant quality feed.

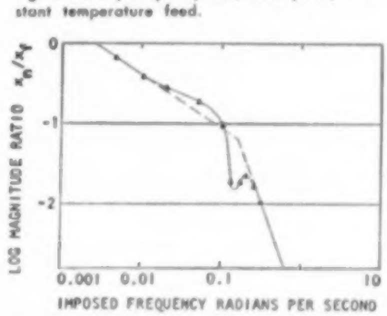

Fig. 26. Frequency response, intermediate plate—stripping section, constant temp. feed.

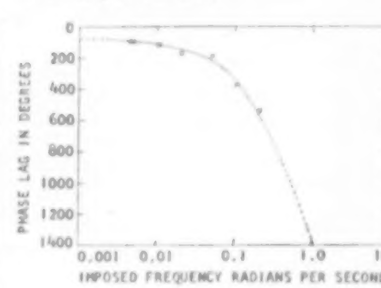

Fig. 26a. Frequency response, intermediate plate—stripping section, constant temp. feed.

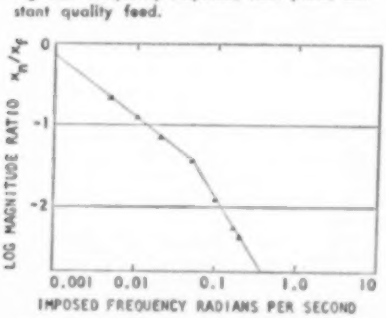

Fig. 27. Frequency response, bottom plate, constant temperature and constant quality feed.

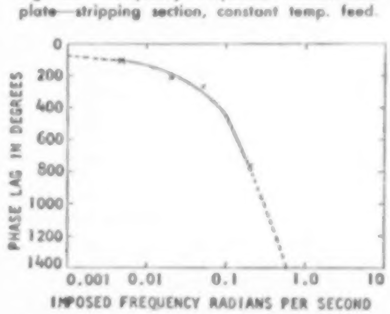

Fig. 27a. Frequency response, bottom plate, constant temperature and constant quality feed.

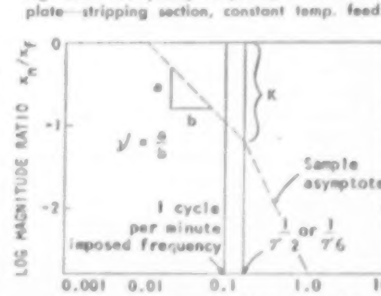

Fig. 28. Illustration of terms in derived plate equations. Magnitude ratio vs. frequency.

What's in

Symposium Series Volume 52

(Number 18, 1956—"Heat Transfer")

Prediction of Heat Transfer Burnout

Louis Bernath

The output of a nuclear reactor or other equipment in which heat transfer plays a major role frequently is limited by the heat-flux density at which the equipment is operated. Raising the heat-flux density increases the output but also may produce burnout or melting of the element across which heat is flowing. This paper presents a generalized correlation that predicts the burnout condition over a wide range of pressures, velocities, geometrical configurations, and heat-flux densities but is limited to the local boiling regime for water. The relation between the local burnout heat flux and the over-all operating conditions of the equipment is developed.

Heat Transfer in the Condensation of Metal Vapors: Mercury and Sodium up to Atmospheric Pressure

Balabhadra Misra and Charles F. Bonilla

It has been assumed that film heat transfer coefficients for the condensation of metal vapors are very high.

However, there are no published data. Owing to new developments in nuclear power and other fields in which metal vapors may have application, a study of the condensation of mercury and sodium vapors was undertaken.

Recorrelation of Data for Convective Heat Transfer between Gases and Single Cylinders with Large Temperature Differences

W. J. M. Douglas and S. W. Churchill

This paper presents the results of a comprehensive reexamination of the data and correlations for convective heat transfer for gases flowing across a cylinder, particularly with respect to large temperature differences between the gas and surface. Attention has been confined to the mean coefficient over the entire circumference.

Pressure Drop During Forced-circulation Boiling

Max Jakob, George Leppert, and J. B. Reynolds

Experimental results are reported for pressure drop during forced-circulation boiling of distilled water in an electrically heated horizontal tube. Empirical correlations are presented for the variation of the static pressure gradient with weight fraction evaporated and with absolute system pressure, together with correlations for the total static pressure drop from the inception of boiling to the end of the heated length as a function of the total fraction evaporated and of absolute pressure.

Heat Transfer and Fluid Friction in a Shell-and-tube Exchanger with a Single Baffle

F. W. Sullivan and O. P. Bergelin

Data are presented for flow through a single annular orifice, for flow through multiple annular orifices in parallel, and for flow around a single baffle both with and without leakage through the baffle. The flow rate across the tube bank, the size of the baffle window, and the annular clearance between tube and baffle are varied. Heating, cooling, and isothermal tests are reported.

A generalized expression is presented for the pressure drop across one baffle section of a tubular exchanger with leakage through the tube holes in the baffle. This expression is used to interpret the data. The annular orifice coefficients are presented in a form suitable for calculating leakage through tube holes in a baffle. The effect of leakage area upon heat transfer and pressure drop is discussed qualitatively.

Heat Transfer Mechanism for Vaporization of Water in a Vertical Tube

C. E. Dengler and J. N. Addoms

The purpose of this research was to study local film coefficients of heat transfer to water during forced-circulation vaporization in a long vertical tube. Primary emphasis was placed upon learning the mechanism of such heat transfer and applying the knowledge so gained toward the correlation of individual local heat transfer coefficients.

The principal conclusions are as follows:

1. The mechanism of heat transfer during vaporization in tubes is primarily convective.
2. Operating variables exert independent and often opposing effects on each of these mechanisms.

The correlations presented here are undoubtedly oversimplified.

Measurement and Prediction of Density Transients in a Volume-heated Boiling System

R. P. Lipkis, C. Liu, and N. Zuber

This paper is concerned with the mixture-density transient response of volume-heated liquid systems subjected to a step increase in the heating rate. This problem is studied experimentally and analytically.

The theoretically predicted density transients compare favorably with the experimental data.

The experimental and analytical results show the high-temperature sensitivity of the density transients and the importance of nucleation to the phenomenon.

Effect of Agitation on the Critical Temperature Difference for a Boiling Liquid

F. S. Pramuk and J. W. Westwater

This work was concerned with the critical temperature difference and the transition region of boiling. Methanol was boiled at atmospheric pressure while being agitated with a 3-in. three-bladed propeller at speeds up to nearly 1,000 rev./min. Heat was supplied by a 6-in. long by ⅜-in. O.D. steam-heated, horizontal, copper tube located within 1 in. of the agitator blades. The critical temperature difference for copper to methanol was about 51° F. and was independent of the degree of agitation. The heat transfer coefficient throughout the entire transition region and also at the critical temperature difference was increased as agitation increased. The maximum increase in heat transfer due to agitation was over 100 per cent. It is now known that agitation can improve the heat transfer coefficient over the entire boiling curve.

A Study of Heat Transfer to Organic Liquids in Single-tube, Natural-circulation Vertical-tube Boilers

S. A. Guerrieri and R. D. Talty

Results of the investigation indicate that the transfer of heat in tube boilers occurs simultaneously by two processes; by convection and by nucleate boiling. The convection process increases in importance with increasing vapor concentration, whereas the nucleate boiling process predominates at low percentage vapor and decreases in importance with increasing vapor concentration. An analysis is presented which accounts for both processes, and a correlation, based on this analysis, is presented which permits the evaluation of the heat transfer coefficient for these two processes.

Circulation Rates and Over-all Temperature Driving Forces in a Vertical Thermosyphon Reboiler

A. I. Johnson

A method is proposed for estimating the over-all temperature driving force (and hence over-all heat transfer coefficients) corresponding to any heat-flux value. The method predicts the existence of the liquid zone and utilizes existing correlations for convection heat transfer to estimate the coefficients for the vaporization zone. The observed behavior of water and hydrocarbon support the proposed theory.

The proposed methods for calculating circulation rates and temperature driving forces correlated much of the recent laboratory data of Piret and Isbin satisfactorily.

This article considers an agitated continuous tank reactor operating under proportional control alone. The conditions for stability of the system are examined. Some methods of nonlinear mechanics are applied and phase plane plots of the complete nonlinear reactor equations are constructed. These calculations are made for perfect proportional control, the numerical solutions having been obtained on the Model 1103 computer (Remington Rand Univac).

STABILITY

of some chemical systems under control

Rutherford Aris and Neal R. Amundson* | University of Minnesota, Minneapolis, Minnesota

Analysis of a continuous agitated tank reactor from the standpoint of stability has been made by the authors in a previous paper (*2*). Such a reactor may be handled by present mathematical methods since the transient behavior is described by a system of simultaneous ordinary differential equations. The treatment of these equations is presented in detail by Minorsky (*4*) and it is necessary only to adapt the techniques described there to the chemical engineering problem. This article is a survey and condensation of a more exhaustive discussion which will appear elsewhere (*1*).

Let a liquid-phase reaction

$$\sum_{j=1}^{n-1} A_j X_j - X = 0$$

be carried on in which a particular reactant designated as X is singled out. Let its concentration at any instant be x, its influent concentration be x_o, and the corresponding concentrations of the other reactants or products be x_j and x_{jo}. Also, if T is the temperature within the reactor and t the time, then the kinetic expression for reaction alone may be expressed as

$$\frac{1}{A_j}\left(\frac{dx_j}{dt}\right)_r = -\left(\frac{dx}{dt}\right)_r = R(x_1, x_2, \ldots, x_{n-1}, x, T)$$

From the stoichiometry of the reaction it is apparent that

$$x_{jo} - x_j = -A_j(x_o - x)$$

so that the reaction rate R may be expressed as a unique function of the concentration x and the temperature T, as

$$R(x, T)$$

in which x_{jo} and x_o appear as fixed parameters.

Thus the unsteady-state equation for conservation of mass may be written as

$$V\frac{dx}{dt} = q(x_o - x) - VR \qquad (1)$$

while the equation for conservation of thermal energy is

$$Vc\rho\frac{dT}{dt} = qc\rho(T_o - T) - VU^* = (-\Delta H)VR \qquad (2)$$

where U^* is the heat removed from the reactor by the cooling coil per unit volume of reaction mixture and $(-\Delta H)$ is the heat evolved per mole of X formed. The reaction rate R and the other parameters have their usual significance.

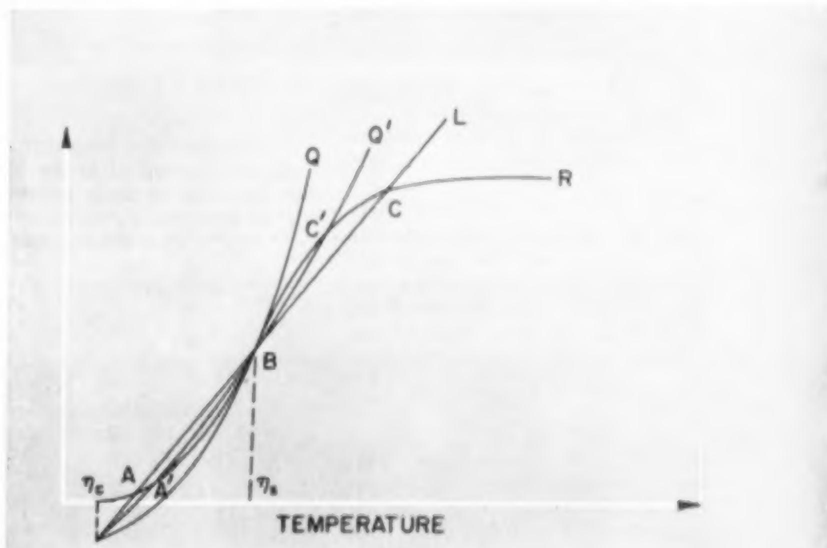

Fig. 1. Heat generation and heat rejection curves.

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In order to investigate the control and the stability of the reactor the solutions to these equations must be studied in some detail. Before one proceeds with this, it is desirable to express these equations in dimensionless form. If

$$\tau = \frac{qt}{V}$$

$$\xi = \frac{x}{x_o}$$

$$\eta = \frac{c\rho T}{-\Delta H x_o}$$

$$P = \frac{VR}{q x_o}$$

$$U = \frac{VU^*}{-\Delta H q x_o}$$

Equations (1) and (2) reduce to

$$\xi'' = \frac{d\xi}{d\tau} = 1 - \xi - P(\xi, \eta) \quad (3)$$

$$\eta'' = \frac{d\eta}{d\tau} = \eta_o - \eta) - P(\xi, \eta) - U(\eta) \quad (4)$$

The study of control and stability revolves around these equations.

It is necessary to say more about the function U^*. U^* has the general form

$$ha(T - T_c')$$

where ha is the heat transfer factor for the cooling coil and T_c' is the average temperature of the coolant in the cooling coil. If the coolant flow rate is denoted by q_c then from a heat balance over the cooling coil it follows that

$$T_c' = \frac{haT + 2q_c\rho_c c_c T_c}{ha + 2q_c\rho_c c_c}$$

where T_c is the inlet coolant temperature. It will be assumed in this paper that the reactor is controlled by regulating the valve on the coolant flow q_c. The reactor must be controlled by measuring deviations from a desired value on the effluent. The question is open whether deviations from the effluent concentration or temperatures should be used for correction of the coolant flow rate.

Local Control of Linearized System

In order to investigate the control of a system, it is customary to consider only small perturbations from the steady state. It seems reasonable then to expect that the rigorous equations describing the system may be linearized about this state and that these simplified equations will describe the transient behavior for sufficiently small perturbations. That this is true was established by Liapounoff (4).

If one defines

$$\alpha = (P_\xi)_s$$

$$\beta = (U_\eta)_s$$

$$\gamma = (-P_\eta)_s$$

$$\delta = (U_{q_c})_s$$

where subscript s refers to the value of these partial derivatives at the steady state; the linearized equations corresponding to Equations (3) and (4) are

$$\xi''^* = -(1+\alpha)\xi^* + \gamma\eta^* \quad (5)$$

$$\eta''^* = -\alpha\xi^* - (1+\beta-\gamma)\eta^* - \delta q_c^* \quad (6)$$

where

$$\xi^* = \xi - \xi_s$$

$$\eta^* = \eta - \eta_s$$

$$q_c^* = q_c - q_{cs}$$

ξ_s, η_s, q_{cs} being the steady-state values.

In order to study Equations (5) and (6) their Laplace transforms will be taken giving

$$(p + 1 + \alpha)\xi'^* - \gamma\eta'^{*\circ} = \xi^{*\circ} \quad (7)$$

$$\alpha\xi'^* + (p + 1 + \beta - \gamma)\eta'^* = \eta^{*\circ} - \delta q'^* \quad (8)$$

If one assumes that control, proportional only, is applied to the coolant then q_c^* is to be made proportional to ξ^* or η^* or that $q'_c{}^*$ is proportional to ξ'^* or η'^*. Thus one may take

a) $q'_c{}^* = \dfrac{K}{\delta}\xi'^*$

b) $q'^* = \dfrac{K}{\delta}\eta'^*$

If the reactor is uncontrolled, i.e., $q_c'^* = 0$, then the solution to Equations (7) and (8) is

$$\Delta(p)\xi'^* = (p + 1 + \beta - \gamma)\xi^{*\circ} + \gamma\eta^{*\circ} \quad (9)$$

$$\Delta(p)\eta'^* = (p + 1 + \alpha)\xi^{*\circ} - \alpha\xi^{*\circ} \quad (10)$$

with

$$\Delta(p) = p^2 + (2 + \alpha + \beta - \gamma)p + (1 + \alpha)(1 + \beta) - \gamma \quad (11)$$

It is clear from this equation that the reactor itself is not stable unless

$$d_e = 2 + \alpha + \beta - \gamma > 0$$

and

$$d_f = (1 + \alpha)(1 + \beta) - \gamma > 0$$

since otherwise the roots of the characteristic equation will have positive real parts and small perturbations will not damp out but will tend to increase.

In the considerations which follow it will be supposed that the state which is being controlled is an unstable one. This is the most interesting case since a stable reactor is one which has a natural tendency to reduce small perturbations. For the unstable reactor d_e or d_f or both are negative and in most cases the latter prevails.

CASE A) CONTROL USING CONCENTRATION DEVIATIONS. $q'^* = \xi'^*K/\delta$.

Here the polynomial $\Delta(p)$ becomes

$$\Delta(p) = p^2 + d_e p + d_f + \gamma K$$

It is clear that if the reactor itself is unstable with $d_e < 0$ then there is no hope of control by this mode. If $d_e > 0$ then a K can be chosen such that $\gamma K + d_f > 0$ and the system stabilized by control.

CASE B) CONTROL USING TEMPERATURE DEVIATIONS. $q'^* = \eta'^*K/\delta$.

The polynomial $\Delta(p)$ is in this case

$$\Delta(p) = p^2 + (d_e + K)p + [d_f + K(1 + \alpha)] \quad (12)$$

Thus by choosing

$$K > \max\,[-d_e, -d_f/(1 + \alpha)]$$

both coefficients may be made positive and stability insured.

Thus in this simple example one sees that it may be futile to try to control on concentration deviations while temperature deviations would be successful. Probably one would not use proportional control alone in any case but it is obvious that more sophisticated control may be handled by the same sort of analysis as that presented above. In the rest of the paper control on temperature will be assumed, and further, the heat transfer function will be taken in the form

$$U = U_s(\eta - \eta_c) + k(\eta - \eta_c)(\eta - \eta_s)$$

Equations (3) and (4) then reduce to

$$\xi'' = 1 - \xi - P(\xi,\eta) \quad (13)$$

$$\eta'' = (1 + U_s)(\bar{\eta} - \eta) - k(\eta - \eta_c)(\eta - \eta_s) - P(\xi, \eta) \quad (14)$$

with

$$\bar{\eta} = \frac{\eta_o + U_s\eta_c}{1 + U_s}$$

As stated in an earlier article (2), the steady states are obtained by solving Equations (13) and (14) simultaneously once the basic parameters have been fixed. This leads to an equation

$$(1 + U_s)(\eta - \bar{\eta}) + k(\eta - \eta_c)(\eta - \eta_s) = -P(\xi_s(\eta), \eta).$$

The right-hand side of this equation is the heat generated by the reaction and shown as R in Figure 1, while the left-hand side is the heat used to heat up

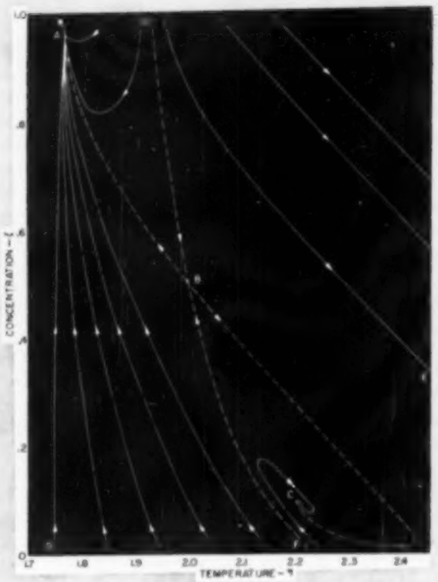

Fig. 2. Phase plane plot for $k = 0$.

Fig. 3. Phase plane plot for $k = 1$.

Fig. 4. Phase plane plot for $k = 4.5$.

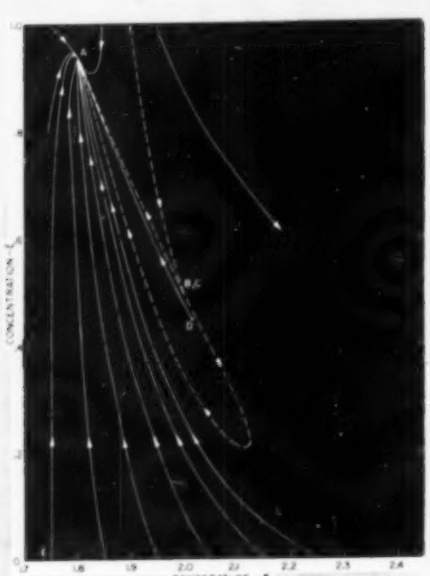

Fig. 5. Phase plane plot for $k = 9$.

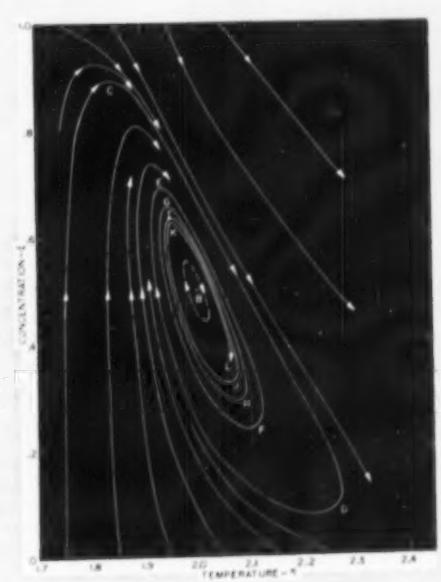

Table 1.

k	Nature	Stability
0–4.5	saddle point	unstable
4.5–5.0	node	unstable
5–9	focus	unstable
9–45	focus	stable
45 →	node	stable

the reactants and the heat rejected to the cooling coil. In the absence of control $k = 0$ and the left-hand side reduces to a straight line L as shown in Figure 1. With $k > 0$ the straight line L becomes a quadratic Q intersecting L at $\eta = \eta_c$ and $\eta = \eta_s$ and increasing in curvature with increasing k. The intersections of Q and R determine the steady states.

Numerical Example and Phase Plane Plot

In order to illustrate the methods above and to make explicit the calculations to follow, a numerical example will be used. Consider a first-order irreversible chemical reaction. The activation energy is 20,000 cal./mole and the unstable point which is to be controlled is at 400° K. or 127° C. The volume of the reactor is 50 liters and the nominal holding time is one minute. A unit of η is 200° K. Other values are chosen such that $\eta_c = \eta_o = \bar{\eta} = 1.75$ and $\eta_s = 2$. Also

$$P(\xi, \eta) = \xi \exp\left[50\left(\frac{1}{2} - \frac{1}{\eta}\right)\right] = \xi Y$$

$$\xi'' = 1 - \xi - \xi Y$$

$$\eta'' = -2(\eta - 1.75) - k(\eta - 1.75)(\eta - 1.75) + \xi Y$$

The parameters of the steady states are

$$\alpha = Y;$$
$$\beta = 1 + k(2\eta - \eta_c - \eta_s);$$
$$\gamma = 50\xi Y/\eta^2$$

At the point $\eta = 2$ which is to be the controlled state

$$\alpha = 1$$

$$\beta = 1 + \frac{k}{4}$$

$$\gamma = 6.25$$

$$d_e = \frac{k - 9}{4}$$

$$d_f = \frac{2k - 9}{4}$$

Hence there is no hope of control until $k > 9$ when both d_e and d_f become positive. The roots of Equation (12) are then

$$-\frac{1}{8}(k - 9) \pm \frac{1}{8}\sqrt{(k-5)(k-45)}$$

Therefore the controlled state, being in general the intermediate steady state, may be characterized as in Table 1.

As shown in the previous paper (2), low-temperature and high-temperature steady states exist in general and as the value of k changes their character will change. It may be shown that the low temperature steady state is stable until $k = 5.9$. The high-temperature steady state is stable until $k = 0.847$ when it becomes unstable. At $k = 5.9$ there is a coalescence of steady states.

Thus the linearization of the rigorous equations will give a relatively complete picture of the nature of the steady states. In order to examine the nature of the states in the large, extensive computations are required since complete solutions of the differential equations are needed. This means that Equations (13) and (14) must be integrated numerically. This is an overwhelming task on a desk calculator if more than a few trajectories are to be computed. It was desired to investigate the whole spectrum of k values for this problem since no complete analysis of this type has appeared in the literature. Approximately thirty different k values were used covering the range from zero to thirty. On each phase plot, that is for a particular k, some ten to twenty trajectories on each plot were computed. A single trajectory may require 1,320 steps, and take 200 sec. to compute including the punching out of some 260 points. These calculations were carried out on the Model 1103 computer of Remington Rand Univac in St. Paul. The complete calculations will be described in another place (1) and only a sample of the results will be presented here.

The differential equations are solved numerically by the Runge-Kutta method adapted to machine use by Gill (3). The error involved in the method is of the order of $(\Delta\tau)^4$.

Figure 2 gives the phase plane plot for $k = 0$ where the ordinate is the dimensionless concentration ξ while the abscissa is the dimensionless temperature. Point A is a stable node, point C is a stable focus, while the point B about which control is to be made is a saddlepoint. All trajectories from the upper right-hand side must spiral into C. This behavior persists until k is about 1 when the high-temperature point becomes an unstable focus, the remainder of the diagram remaining much the same. Figure 3 shows the plot for $k = 1$. Any point such as J must pass through the narrow strait between HB and DE.

In Figure 4, $k = 4.5$, all trajectories lead to A, those outside the lobe making a circuitous journey perhaps. At $k = 9$, Figure 5 a stable limit cycle has developed and the approach to this limit cycle is very slow. As k increases, the limit cycle decreases in diameter and eventually disappears leaving a stable focus. This focus, however, is a slow spiral giving in practice poor control. Not until $k = 30$ is the control adequate when a strong focus persists. Finally, at $k = 45$ and beyond, a stable node is found giving strong control.

Acknowledgment

The authors are indebted to the Computing Center of the University of Minnesota and particularly to R. A. Wonderly for aid in the programming of the computer. The contribution of machine time by Remington Rand Univac is gratefully acknowledged.

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Notation

A_j = stoichiometric coefficient
c = specific heat
ha = heat transfer coefficient times area
K = proportional control constant
k = a constant proportional to K
P = dimensionless reaction rate
q = influent flow rate
R = reaction rate
T = temperature
t = time
U^* = heat rejection rate to cooling coil
U = dimensionless heat rejection rate
V = volume of reactor
X, X_j = chemical species
x, x_j = concentration of X, X_j

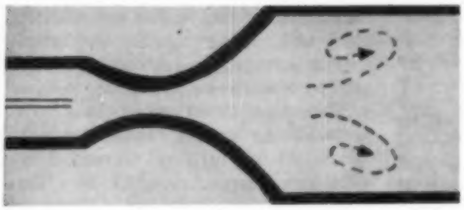
Greek letters

$\alpha, \beta, \gamma, \delta$ = partial derivatives defined in text
ρ = density
η = dimensionless temperature
ξ = dimensionless concentration
τ = dimensionless time

′ and bar refer to Laplace transform
* refers to a deviation
″ refers to first time derivative
° refers to initial condition

subscripts

c refers to coolant
s refers to steady state
o refers to influent



JET SPRAY DRYER

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A unique design of spray dryer has been built and operated. Its features include the introduction of the solution or suspension to be dried directly into a hot, high-velocity gas stream. This arrangement results in atomization to extremely small particles and in unusually high rates of drying. The time that the particles are subjected to the elevated temperatures used in drying is greatly reduced, and the size of equipment required for a given drying capacity is also greatly reduced. The hot primary air used for atomization and evaporation is surrounded by a stream of secondary air with a lower temperature and a lower velocity. The purpose of the secondary-air stream is to control the pattern of flow through the dryer by supplying the entrainment demand of the primary jet and thus to prevent recycling of the already dried particles back into the high temperature zone. This permits the drying to take place in a tube about 6 in. or more in diameter instead of in the usual large drying chamber. The high rate of drying with its corresponding short time of contact, and the controlled path of the individual drying particles through the dryer make this design especially suitable for drying highly heat-sensitive materials such as milk and food, pharmaceutical and biological products. A jet dryer of improved design has been constructed and tested at Purdue University *(23, 24)*. However, no experiments on heat-sensitive materials are reported here. Only preliminary runs have been made on the dryer at the University of Illinois. In some of these a solution of sodium sulfate was used as a feed and in others water was used. The special drying conditions provided by this dryer can be obtained without an appreciable increase in heat requirements, but because of the high velocity of the primary air, the power requirements are somewhat greater than in conventional spray dryers.

Atomization and spray drying have recently been reviewed by Marshall *(22)* who gives considerable information about the principles underlying the design of many types of spray dryers. The jet spray dryer is an outgrowth of the high-velocity vaporizer developed during World War II which used the principle of the Venturi atomizer *(10)*. This is similar to the design used in automobile carburetors, and was partially investigated by several others *(2, 19, 21, 28)*.

Thermally unstable material such as petroleum oils, organic dyes, and liquid mustard gas *(25)* were successfully evaporated in the high-velocity vaporizer by feeding them into a very hot flue gas at temperatures as high as 1,800-2,000° F. which flowed through the throat of a Venturi tube at a high velocity of the order of 1,000 ft./sec. The liquid was atomized to small droplets of about 40 μ-diam. or less, and was then completely vaporized in as short a time as 2 to 10 millisec. The hot gases issued almost immediately into the cold atmosphere and the vapors were cooled by jet entrainment to atmospheric temperatures where the compounds were stable. Tests indicated that these liquids withstood the treatment with hot gas with essentially no decomposition. The combination of extremely fine atomization, high heat-transfer rates, and the cooling of the hot gases by the absorption of the latent heat of evaporation of the liquid made it possible to subject these substances to gas temperatures which would otherwise cause their complete chemical breakdown.

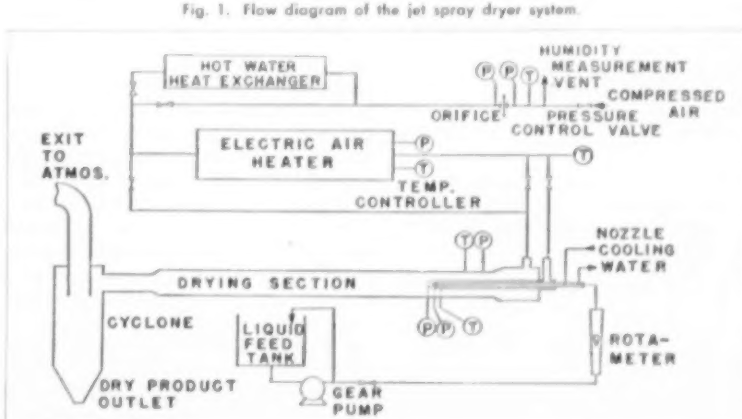
In the high-velocity vaporizer, the liquid droplets were completely evaporated and thus there was no solid residue from the atomized particles. In order to adapt these principles to spray drying, it was found necessary to make some basic changes in the design in order to prevent the partially dried semisolid particles from depositing on the inner walls of the apparatus. A number of design modifications were considered and tried before the present successful arrangement was discovered. These unsuccessful designs will be discussed later. Other investigations which dealt with a free jet *(7, 17, 33)*, a jet issuing into a duct *(3, 4, 6, 15)*, and the accompanying flow patterns, heat transfer, mass transfer, and momentum transfer *(1)* have contributed a sound basis for the design of the jet spray dryer.

Experimental Apparatus

A flow diagram of the experimental system is shown in Figure 1.

An air compressor delivering at 100 lb./sq. in. was used. This pressure was reduced to about 7 lb./sq. in. gauge by a pressure-reducing valve, and the air then flowed through an orifice meter provided with a set of calibrated orifices. The air next passed through a heat exchanger where it was heated to about 200° F. by hot water. An electric heater with a

Fig. 1. Flow diagram of the jet spray dryer system.



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capacity of about 70,000 B.t.u./hr. was next in line. By-passes were provided around both of these heaters, and various combinations of primary- and secondary-air temperatures were possible.

The hot primary air from the electric air heater was delivered to the head of the dryer and flowed through a central tube. The remainder of the air at a lower temperature consisting of a mixture of air from the electric heater and air that had by-passed this heater was fed to the secondary-air entrance section of the dryer. The liquid to be dried was fed by a gear pump and passed through a rotameter to the liquid-injection tube in the center of the primary-air tube which leads to the primary-air nozzle. Uniform and steady operation of the gear pump was essential since slight fluctuations in the feeding rate cause comparable fluctuations in the air temperature in the drying section.

The drying tube was horizontal but because of the high velocities and small particle size no adverse effects from gravity were observed. The distance of fall of the droplets during their total residence time in the drying section was negligible. The mixture of dried product and air flowed through a cyclone for the product removal.

The spray dryer was constructed in sections. The drying section has been mentioned. Upstream from this section was a secondary-air-approach section and a secondary-air-entrance section. Inside the air-approach and air-entrance sections were the atomizing nozzle and the primary-air tube leading to this nozzle. Inside the primary-air tube was the liquid injector.

LIQUID INJECTOR

The liquid injector consisted of a central tube for carrying the feed solution and two outside concentric tubes for water cooling. Hot atomizing air at 400 to 600° F. flowed in the annulus around the liquid injector. A 1/10-in. diam. hole served as a passage for injecting the feed into the high-velocity primary-air stream at the nozzle. The liquid discharge velocity at the nozzle was low and presumably has no effect on the drop size resulting from atomization. When the liquid injector was operated with no air flowing through the primary tube, a clear solid stream was produced for several feet before it broke up.

PRIMARY-AIR TUBE—ATOMIZING NOZZLE

The atomizing nozzle is at the end of the primary-air tube. The inner profile of the nozzle conforms with the specifications (*5*) for an A.S.M.E. long-radius low-ratio nozzle with a throat diameter of 0.500 in. The outer profile is streamlined to some extent in order to avoid a dead air space and an undesirable eddy. The shape of the inner profile and the dimensions were chosen with the design of the nozzle used by Nukiyama and Tanasawa in their atomization experiments (*26, 27*) in mind. Thus the Nukiyama and Tanasawa equations for drop size apply to this design and may be used to predict the initial drop size. The proper distribution of the atomized particles is extremely sensitive to the careful centering of the liquid injector in the nozzle. Failure to center the injector caused asymmetrical spray patterns in the drying chamber. If the liquid strikes the hot atomizing nozzle, it will instantly deposit a cake of dry product, and the equipment must then be shut down. Special precautions were taken to center the liquid injector. Similar precautions were taken to center the nozzle. This complete assembly operated successfully.

DRYING AND SECONDARY-AIR SECTIONS

The drying section and secondary-air sections were fabricated from sheet steel rolled and butt welded at the seam.

This method provided a drying section which was never more than 1/32 in. from the 6-in. I.D. and gave a smooth inner surface. There were four of these sections.

The drying section was a straight tube 62 in. long and the nozzle exit was placed flush with the entrance to this section. The primary-air tube and nozzle were located on the axis of this tube at the upstream end. The other sections were a secondary-air-approach section 16 in. long by 6 in. I.D., an entrance section 9 in. long by 8 in. I.D., and a 2-in. long conical transition section connecting the 8-in. and 6-in. diam. tubes. A coarse screen was placed at the beginning of the approach section to aid in providing a uniform distribution of air throughout the secondary-air annulus. Velocity and temperature explorations of the secondary air at the exit from the approach sections showed no detectable nonuniform distribution. The cyclone used in the system was not designed (*18*) to remove the small particles in the 2- to 10-μ diam. range with high efficiency.

Measurements were made of the flow rate of the primary air, total air, and liquid feed at the positions shown in Figure 1. Pressures and temperatures were also measured at points in the system as indicated in the flow diagram. In addition, three probes were used to obtain readings at a number of sections in the drying tube. These included a probe used with a pneumatic thermometer, an impact tube used both for velocity measurements and as a liquid collector, and a third probe containing a thermocouple covered with cotton to obtain wet-bulb temperatures. The pneumatic thermometer probe was used to obtain dry-bulb temperatures and air humidities in the presence of wet liquid droplets. This instrument operated on the principle that by measuring the pressure drop across a small orifice in the end of the probe tube and separately the rate of flow through this orifice, one could calculate the dry-bulb temperature of the air entering the probe. The rest of the instrument and its design and calibration are described elsewhere (*9*).

The primary-air flow rate was metered by using the atomizing nozzle as an air-flow meter. Temperatures were measured by iron-constantan thermocouples. A series of holes was provided along the bottom side of the drying section. An electromagnetic probe holder was moved from one hole to another, and was held snugly against the outer curved wall of the drying section by the electromagnet. The probes were held in the probe holder so that measurements were always made along a diameter of the drying section, with the radial position of the probe fixed for any one measurement by a set screw in the holder and its position given by a scale on the probe. Various effects on the impact-tube and liquid-droplet-collector readings were considered, such as those caused by the viscosity, compressibility, turbulence, or angle of attack of the air, and by the presence of solid or liquid particles in the gas stream. Wherever possible, errors due to those effects were minimized in the design and handling of the instruments. Errors of appreciable magnitude were likely due only to the effects of turbulence and the presence of the solid particles. In the first case, the error probably did not exceed 8% and except at a few points, was considerably less than this, while in the second case the maximum error was about 2%.

Theory

The effectiveness of the jet spray dryer in producing unusually high rates of drying with their resultant short drying time, in ensuring a once-through treatment for each drying particle, and in reducing the volume of the drying chamber is due to (a) the great increase in the surface area of the droplets per unit weight of feed which is brought about by the initial fine atomization; (b) the increase in the heat-transfer coefficient to the droplets (and also the diffusion coefficient for the vapor from the droplet surface), which results from the fine atomization; (c) the immediate availability of the heat for supplying the latent heat of evaporation in the hot atomizing air which surrounds the particles as they are formed; (d) the effective mixing of these particles with the hot primary air because of the high turbulence generated by the primary air jet; (e) the controlled path of flow through the tubular drying chamber, ensured by supplying sufficient secondary air to meet the entrainment demands of the primary-air jet, thus eliminating large

back-mixing eddies, and preventing the return of sensitive-dried particles from the low-temperature downstream regions to the high-temperature regions near the nozzle. The quantitative effects of some of these features will be indicated.

The conditions for producing fine atomization by injecting a liquid into a high-velocity gas stream are related to the mean droplet diameter by the equation proposed by Nukiyama and Tanasawa based on their extensive atomization experiments (*26*). The volume-surface-mean diameter of the drops (*31*) produced in this type of atomization is given by the equation:

$$D_{VS} = \frac{585}{V'}\sqrt{\frac{\sigma_l}{\rho_l}} + 597\left(\frac{\mu_l}{\sigma_l\rho_l}\right)^{0.45}\left(1{,}000\,\frac{Q_d}{Q_g}\right)^{1.5} \qquad (1)$$

For water at about room temperature when the ratio Q_d/Q_g is of the order of 10^{-4}, the last term is negligible and this equation then reduces to:

$$D_{VS} = \frac{16{,}400}{V'} \qquad (2)$$

Equation (2) applies if the ratio of air to water exceeds about 46 cu.ft. of air/lb. water or with air at about 400° F., this is 2 lb. air/lb. water. Equation (2) indicates that an air velocity of about 1,000 ft./sec. is necessary to produce drops with a mean diameter of about 16μ. An air velocity of 100 ft./sec. would produce droplets with a mean diameter of 164μ. The surface area per pound of liquid and the heat-transfer coefficient, both increase greatly when the drop size is less than about 20μ.

The rate of heat transfer per pound of liquid droplets at any instant may be represented by

$$q = hA_d\Delta t \qquad (3)$$

where A_d is the surface area per pound. This may be calculated directly from the average drop size, D_{VS}. A_d in square feet is equal to $29{,}300/D_{VS}$. Ranz and Marshall (*29, 30*) have shown that the heat-transfer coefficient to small droplets is given by

$$\frac{hD'}{k} = 2.0 + 0.6\left(\frac{D'V'\rho_g}{\mu_g}\right)^{1/2}\left(\frac{c_p\mu}{k}\right)^{1/3} \qquad (4)$$

The rate of heat transfer per unit temperature difference per pound of water $q/\Delta t = hA_d$ is given by

$$hA_d = \frac{8.9 \times 10^{9}}{D_{VS}^{2}}k\left[2.0 + 0.0011\left(\frac{D_{VS}V'\rho_g}{\mu}\right)^{1/2}\right] \qquad (5)$$

Minimum and maximum values possible for hA_d have been calculated for the case where the average temperature of the air film is 400° F. These two values were found by assuming, respectively, a velocity of the air relative to the droplets of zero and a velocity of air relative to the droplets equal to the atomizing velocity required to produce various mean drop sizes. These minimum and maximum values of hA_d are shown in Figure 2 vs. the average drop size. The great increase in the rate of heat transfer per unit temperature difference at the small values of drop size is evident. The rate of heat transfer at the maximum velocity is about four times that at zero velocity at any drop size. The time required to dry a 100-μ particle will be at least twenty times that required to dry a 20-μ particle, and the drying time decreases rapidly with decreasing particle size below 20μ.

The accurate calculation of the drying time of the atomized particles requires an integration which includes the effect of the initial drop-size spectrum, variation in the drop diameters as drying progresses, variation in the air temperature as latent heat is absorbed, variation in the air velocity both radially and axially in the drying chamber, and variation in the turbulence level. The transport equations developed by others (*7*) were applied in this case and a schedule was prepared for carrying out the calculations on an electronic computer but these computations were not made. Related computer computations have been presented recently by Starkman (*32*). To determine the order of magnitude of the drying time, approximate calculations have been made to indicate a probable maximum and minimum time for the drying of a 20-μ mean drop size.

The results are shown in Table 1. The droplet diameter was considered constant until drying was complete, and a minimum time was calculated using the values of hA_d and of Δt corresponding to the high velocities and high temperature at the point of atomization. The distance the droplets would travel during the calculated drying time if the velocity of the stream was constant at 850 ft./sec. is also indicated. A maximum value of the drying time was calculated by using the minimum values of hA_d and of Δt which would occur at the outlet of the dryer where the drops travel at the same velocity as the air and the air temperature is a minimum. The distance traveled during drying under these conditions was estimated by using a constant velocity of 100 ft./sec. through the dryer. The drying time based on these calculations

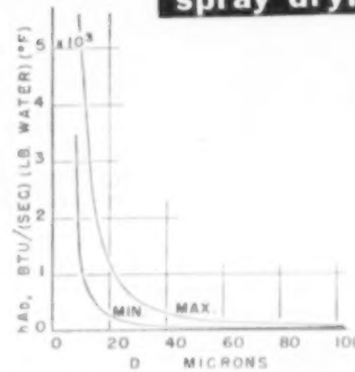

Fig. 2. Effect of drop size on rate of heat transfer per unit temperature difference.

is in the range from 1 to 60 millisec. and the distance traveled by the 20-μ drops during drying is from 5 to 6 ft. as a maximum.

The feed rate must be adjusted so that the latent heat of evaporation absorbs sufficient sensible heat from the primary- and secondary-air streams to reduce their temperature at the dryer exit to a low level where deterioration of the product is very slow. During the early part of the drying process, the water content of the droplets ensures that their temperature will not rise above the wet-bulb temperature, and this protects them from overheating. After the moisture content has been reduced below a certain minimum level, the temperature of the droplets will rise and approach that of the dry-bulb temperature of the gas stream. When this point in the dryer is reached, the dry-bulb temperature must be low enough to avoid thermal damage to the product. It is relatively easy to provide this type of temperature control in this dryer and this is one of its advantages. Because of this temperature control it is possible to use a primary-air stream at unusually high temperatures without damaging heat-sensitive materials. The power requirement for this dryer is likely to be somewhat larger than that of other designs since a large amount of primary air is used at pressures of a few pounds per square inch. A Venturi shape to reduce the power was tried and abandoned because of the complications arising from the deposition of solids within the divergent section.

The reduction in the size of the drying section or drying chamber compared with conventional designs is very marked in the jet spray dryer. The volume of the drying chamber is proportional to the drying time, and this has been reduced in the order of 1/100 of that used in other spray dry-

ers. The volume of a spray dryer with a contrifugal disk atomizer is reported to be in the range from 1.8 to 20 cu.ft./(lb.)(hr.) of evaporation *(27)*. In the Turbulaire spray dryer this is reduced to 0.33 to 0.67. In the jet spray dryer a further reduction was obtained to 0.037 to 0.051 with an indication that operation at 0.018 may be satisfactory.

Results

Elgert *(13)* made twenty-two runs with the jet spray dryer. Two of these were made for purposes of adjustment only. In runs 3, 7, 17, 20, and 22 the feed was 10% sodium sulfate. In the rest of his runs the feed was distilled water. The runs with water served to indicate the primary- and secondary-air flow rates and temperatures which were most likely to be suitable. In runs 3 and 7 the tip of the feed injector was in a position 1 3/32 in. upstream from the end of the nozzle, and severe deposition of solids took place in the nozzle. The feed injector was then moved to 0.50 in. upstream from the end of the nozzle, and deposition within the nozzle was eliminated.

Results from the runs drying sodium-sulfate solution are tabulated in Table 2. Run 17 lasted for 1½ hr. and was relatively satisfactory. In run 20 a heavy deposit occurred on the bottom of the drying section between 17.5 and 20 in. downstream after 4 hr. of operation. When the alignment of the primary-air nozzle was changed after run 20, the amount of deposition decreased considerably. Cake deposition on the walls of the drying section in run 22 was nearly eliminated and after 4 hr. of operation there was only one spot at 17 in. from the nozzle where a lump had grown. The tendency for the feed to be irregular at times, due to the erratic operation of the by-pass valve used to control the feed rate, accounts for the deposition of undried material. Once a deposit starts it has a tendency to grow. A completely steady feed is required for the successful operation of this dryer. A drying tube with a larger diameter would cause the control to be less critical. Supplying both primary and secondary air from the same limited air supply, and passing both through the same heaters seriously restricted the control of operating conditions.

The particle-size distribution of the dried product from runs 3, 7, and 17 was measured by Hilvety *(16)*. The air and solid particles from the drying

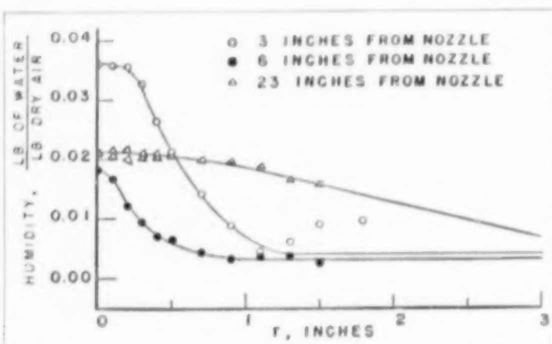

Fig. 4. Radial distribution of humidity 3, 6, and 23 in. from nozzle exit.

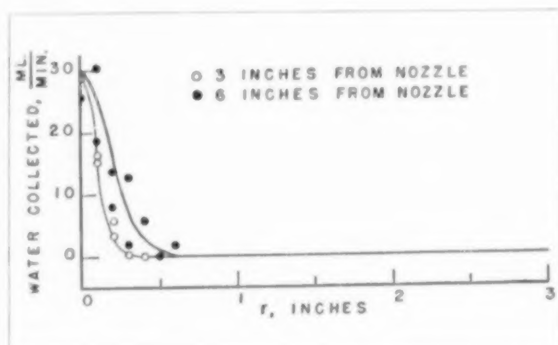

Fig. 5. Radial distribution of liquid-water concentration 3 and 6 in. from nozzle exit.

Table 1.—Estimated Evaporation Time for 20 Micron Drops

Temperature Inlet air °F.	Temperature Outlet air °F.	Minimum Time millisec.	Minimum Distance traveled at 820 ft./sec. ft.	Maximum Time millisec.	Maximum Distance traveled at 100 ft./sec. ft.
1,000	206	0.97	0.80	62	6.2
800	204	1.25	1.03	56	5.6
700	202	1.47	1.21	54	5.4
600	200	1.77	1.45	51	5.1
500	196	2.22	1.82	49	4.9
400	193	2.95	2.42	46	4.6
300	188	4.34	3.56	44	4.4
250	179	5.67	4.65	44	4.4
200	171	8.06	6.61	45	4.5

Table 2.—Spray Drying 10% Sodium Sulfate Solution *

Run No.	Primary air lb./hr.	Ratio lb. secondary air to lb. primary air	Nozzle velocity ft./sec.	Water evaporated lb./hr.	Temperature °F. Primary air	Temperature °F. Secondary air
3	. . .	. . . .	. . .	22.5	. . .	. . .
7	. . .	. . . .	. . .	16.0	. . .	. . .
17	178	6.74	737	33	439	303
20a	205	6.66	839	23.5	444	228
b	202	6.70	841	23.5	452	227
c	200	6.78	837	21.5	450	227
d	201	6.81	836	22.0	449	225
22a	187	7.23	812	30.3	471	319
b	191	7.18	810	30.3	473	320
c	183	7.48	797	31.2	473	320
d	183	7.48	800	30.5	474	320

Duration of run 17, 1 hr. 35 min.; run 20, 4 hr. 35 min.; run 22, 4 hr.

* Data by O. J. Elgert (13).

Table 2.—(Continued)—Spray Drying 10% Sodium Sulfate Solution *

Run No.	Outlet air temperatures °F. Dry bulb (measured)	Dry bulb (calculated)	Wet bulb measured	Wet bulb calculated	Heat supplied B.t.u./lb. water
3	275	270	116	112	3,770
7	260	250	104	104	5,400
17	224	220	112	109	2,940
20a	186	185	106	100	3,130
b	189	185	106	100	3,070
c	197	195	107	100	3,350
d	198	190	108	99	3,270
22a	228	240	110	108	3,380
b	228	245	108	108	3,380
c	230	240	111	109	3,290
d	238	245	112	109	3,290

Duration of run 17, 1 hr. 35 min.; run 20, 4 hr. 35 min.; run 22, 4 hr.

* Data by O. J. Elgert (13).

Table 3.—Operating Conditions for Final Runs

			%
Total air flow rate	1,266	lb./hr.	(± 1.1)
Primary-air flow rate	191	"	(± 1.6)
Secondary-air flow rate	1,075	"	(± 1.5)
Total water flow rate	19.6	"	(± 2.0)
Primary-air temperature—upstream of nozzle	475	°F.	(± 1.9)
nozzle throat (calculated)	411	"	(± 2.2)
Secondary-air temperature	283	"	(± 3.2)
Primary-air velocity-nozzle throat	853	ft./sec.	(± 1.1)
Secondary-air velocity	28.9	"	(± 1.38)
Volume/surface mean drop size (not measured)	20	μ	(± 50)
Entering humidity	0.004	lb. water/lb. dry air	

section were allowed to flow through a box with both ends open. The ends were then closed suddenly and a sample of the dried particles suspended in air was trapped in the box. The box was set aside and the particles settled on a glass microscope slide on the bottom of the box. This slide had been covered until the ends of the box were closed and the cover was then withdrawn. The volume-surface-mean diameters were determined from the number-size relation obtained by counting under a microscope. These were 4.95, 4.78, and 4.41μ for the three runs with nozzle velocities of 590, 605, and 717 ft./sec. respectively. The mean deviation σ from each mean diameter was 1.28, 1.45 and 1.50 respectively.

Based on the early runs by Elgert, a single combination of operating conditions was chosen and repeated runs extending over six days were made by Coldren (*8*) under these conditions. Distilled water was used as feed. These runs did not test the effectiveness of the apparatus as a spray dryer. Their function was to permit measurements within the drying chamber to follow the changes taking place in this section. These measurements were made at six cross-sections of the 62-in. long drying chamber, 3, 5, 6, 13, 18, and 23 in. downstream from the end of the primary-air nozzle, each along a vertical radius from the axis to the bottom of the duct. A few measurements were made above the axis. Some of these were symmetrical with the measurements made below the axis and some were not. The dynamic pressure (with the impact tube), the dry-bulb temperature (with the pneumatic thermometer or a thermocouple probe), the wet-bulb temperature (with the cotton-covered thermocouple), the liquid-water concentration (with the collection tube), and the water-vapor concentration (with the pneumatic-thermometer or from wet- and dry-bulb temperatures) were measured.

The operating conditions for these final runs are shown in Table 3. The ratio of weight of secondary air to weight of primary air was 5.65. Small negative impact pressures were observed at 3 and 6 in. in the region nearer the wall and outside the jet of primary air. This may indicate that a higher ratio of secondary to primary air would be needed to satisfy the entrainment demand of the primary-air jet and completely avoid recycling within the drying chamber. Typical profiles of temperature are shown in Figure 3 at 3, 6, and 23 in. The temperature from the pneumatic thermometer, and from the cotton-covered-thermocouple probe are shown together with lines indicating the probable wet- and dry-bulb temperatures. The error in dry-bulb temperatures is not more than 30°F. and probably not more than 15°F. This is apparently the first time that dry-bulb temperatures such as these have been measured in the presence of a wet mist. In the primary-air jet and in the presence of the wet droplets, the pneumatic thermometer was used to measure the dry-bulb temperature. Outside this region in the secondary-air stream the cotton-covered thermocouple was dry and measured the dry-bulb temperature. The wet-bulb temperature was measured by the cotton-covered thermocouple in the region where water droplets were present to keep it thoroughly wet. The wet-bulb temperature of the secondary air was calculated from its dry-bulb temperature and the inlet humidity of 0.004 lb. water/lb. of dry air. The sharp increase in the temperature measured by the cotton-covered thermocouple as it is moved away from the axis was a sensitive indication of the boundary of the region containing water droplets. This is shown in Figure 3. The more gradual increase in this measurement at 23 in. downstream was not definitely indicative of this boundary and is not explained. The humidity of the air was also measured by the pneumatic thermometer in the presence of the water droplets. The radial distribution of humidity at 3, 6, and 23 in. is shown in Figure 4. Liquid-water concentrations determined by the collection probe are shown in Figure 5 at 3 and 6 in. No water was collected by the probe at 23 in.

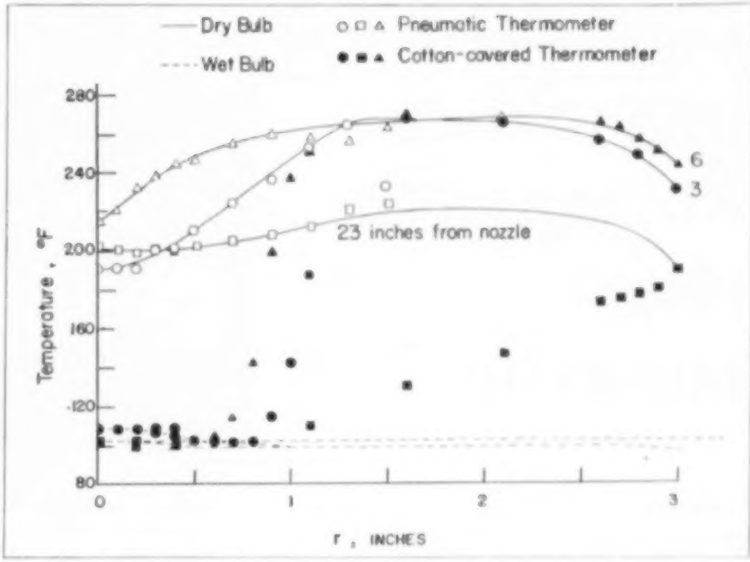

Fig. 3. Radial distribution of temperature 3 in. from nozzle exit.
Radial distribution of temperature 6 in. from nozzle exit.
Radial distribution of temperature 23 in. from nozzle exit.

The measurements already described were made along a radius at several sections of the drying chamber. By assuming complete symmetry at each section the fluxes of several quantities as they vary with radial position may be determined. The flux vs. the radius at each section was calculated and plotted for momentum, for water (liquid and vapor), and for heat (both sensible and latent). The area under these curves should be the same for any one quantity since the quantities are conservative. These areas varied from one curve to another indicating that there were inconsistencies in the measurements or that the flow was not symmetrical.

Development and Comparison

A number of dryer designs were built and tested prior to the present successful design. A brief discussion of these earlier models and the features that caused them to be unsuccessful is of value in clarifying the essential features of the present design. These earlier designs are shown diagrammatically in Figure 6. In design *A* a modification of the high-velocity vaporizer (*10*) originally used for the evaporation of a pure liquid to produce smokes and aerosols was tested (*14*). The chief difficulty encountered here was the excessive deposition of solid on the walls of the diffuser section downstream from the point of feed injection. An attempt was made to avoid this difficulty by changing the shape of the diffuser section in accordance with the work of Conroy (*11*) on the atomization of liquid sulfur in a sulfur

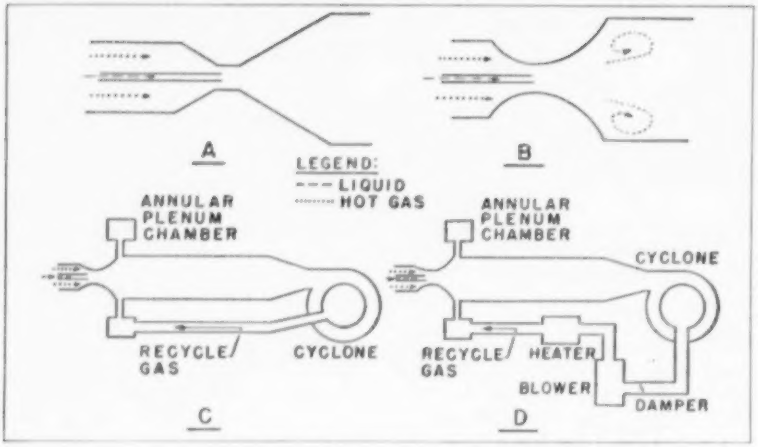

Fig. 6. Early jet spray dryer designs.

burner. His results indicated that such deposition could be eliminated or minimized if the diffuser section is bell or trumpet shaped.

The design shown at *B* was built and tested by Prosche (*28*) using sodium-sulfate solution. However, flow separation (*20*) occurred in the bell-shaped diffuser section, and deposition again occurred on all of these surfaces. The results of the experiments with free jets (*33*) and with a jet in a duct (*3*) made it clear that the problem of deposition could not be solved by changing the shape of the downstream section alone. It would be necessary to supply air for entrainment by the high-velocity jet in order to prevent air from being sucked back along the wall from positions further downstream. It is this eddy induced by the high-velocity jet which carries the partially dried particles back and deposits them on all surfaces.

The next design, shown at *C*, provided for supplying entrainment air from an annular duct or a plenum chamber. This design was operated also by Prosche. When the proper amount of air to meet the entrainment demand was supplied, deposition of the wet product around the nozzle was eliminated. However, deposition still occurred further downstream in the drying section. The air for entrainment in this design was supplied entirely by the pumping action of the jet itself, and it was felt that the inability to control the amount and temperature of the secondary-air stream contributed to the unsuccessful operation.

In design *D* a blower and heater were incorporated in the secondary-air line which conducted the recycled air from the cyclone. This provided an independent control of the amount and temperature of the secondary-air stream. Design *D* was operated (*12*) with several rates of recycled air and the results showed improvement but were not satisfactory. All previous forms of deposition of wet product could be prevented by increasing the recycle rates, however, a deposit now formed several inches downstream from the annular recycled-air entrance. This was apparently due to the undesirable air-circulation patterns set up by bringing the recycled air in at right angles to the primary-air stream. It thus became evident that completely separate primary- and secondary-air streams would be needed and that these should enter in a parallel-flow concentric arrangement with as uniform a velocity distribution prior to the mixing of the two streams as was possible. With these principles clearly established, the present successful design of dryer was built and operated.

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Notation

A_d = surface area of droplets per pound, sq.ft./lb.
c_p = specific heat of gas, B.t.u./(lb.)(° F.)
D' = droplet diameter, ft.
D_{vs} = volume-surface-mean diameter, μ
h = heat-transfer coefficient B.t.u./(hr.)(sq.ft.)(° F.)
k = thermal conductivity of gas, B.t.u./(hr.)(ft.)(° F.)
q = rate of heat transfer, B.t.u./hr.
Q_d = volume rate of liquid atomized
Q_g = volume rate of air used for atomization
t = temperature, ° F.
V = relative velocity between air and liquid, ft./sec.; V', m./sec.

Greek Letters

μ_l = viscosity of the liquid, g./(cm.)(sec.)
μ_g = viscosity of gas, lb./(ft.)(sec.)
ρ_l = density of the liquid, g./cc.
ρ_g = density of the gas, lb./cu.ft.
σ_l = surface tension of liquid, dynes/cm.

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Magnesium extraction process for PLUTONIUM SEPARATION FROM URANIUM

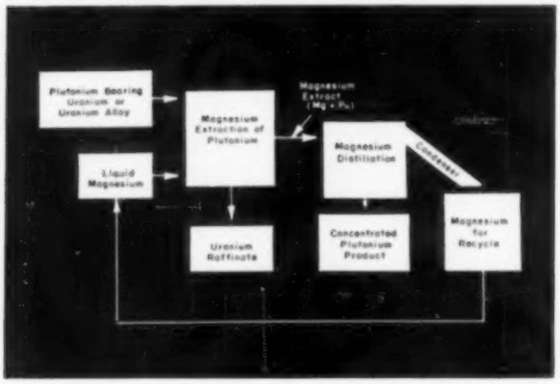

Fig. 1. Schematic flow sheet for magnesium extraction of plutonium.

A high-temperature extraction process for the separation of plutonium from nuclear reactor core and blanket materials is described and data are presented. Molten magnesium, which is immiscible with molten uranium, may be used to extract plutonium from uranium. Plutonium distributes between magnesium and uranium or the lower melting uranium alloys such as uranium chromium and uranium iron with a distribution coefficient of about 2 (weight basis) in favor of the magnesium. The plutonium may be separated from the magnesium by volatilization of the magnesium. Auxiliary operations such as molten-metal transfer, phase separation, and sampling are also discussed.

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A promising high-temperature process for separation of plutonium from nuclear reactor core and blanket materials is the extraction of plutonium from the melted materials with molten magnesium. This process was first described by Lawroski (*1*) and Motta (*2*), and the purpose of this paper is to report subsequent work at Argonne National Laboratory, which has brought it into a pilot plant stage of development. The principles of the process are illustrated by the schematic flow sheet shown in Figure 1. In essence, the process consists of extraction of plutonium from molten uranium into molten magnesium and subsequent distillation of the magnesium away from the extracted plutonium.

Several physical properties of the constituent metals are important in this process. Melting- and boiling-point data are given in Table I. A phase diagram of the uranium-magnesium system, shown in Figure 2 (*3, 4*) indicates that uranium is soluble in magnesium to the extent of about 0.1 to 0.2 wt. % at temperatures of 1,000° to 1,400° C. Magnesium is soluble in uranium to the extent of only 0.004 wt. % at 1,150° C.

Materials of Construction

A formidable problem exists for the magnesium extraction process in regard to materials of construction, which must be of two kinds: (1) materials which will withstand attack by molten magnesium, and (2) materials which will withstand attack by the molten uranium-magnesium system. A number of materials may be used to contain molten magnesium (*5, 6*) but very few are satisfactory for containing the molten uranium-magnesium system.

MOLTEN MAGNESIUM

In several process situations, that is, magnesium condenser and magnesium storage vessels, molten magnesium must be contained at temperatures only slightly above the melting point. In other situations, however, materials compatible with magnesium at temperatures up to 1,150° C. must be used, that is, process lines from the extraction equipment.

At the lower temperatures (up to 700° C.) there are available results of considerable industrial experience on materials of construction (*4, 5*). Under these conditions commonly used materials of construction are cast iron, low-carbon steels (such as S.A.E. 1010 and 1020), high-chromium steels (such as type 420 and type 446), and graphite. The high-chrome steels have the added advantage of good resistance to air oxidation on the exterior. Because of the high solubility of nickel in magnesium, the chrome-nickel stainless steels are attacked by liquid magnesium; however, experimental apparatus constructed of type-347 stainless (an 18-8, niobium-stabilized stainless) has given good service in low-temperature applications (~700° C.).

The refractory metals—tantalum, titanium, niobium, tungsten, molybdenum, and chromium—are reported to have good resistance to attack by magnesium up to about 800° C. Molybdenum has been checked at 700° C. and tantalum up to 1,150° C. and no attack was evident visually in either case.

Alumina, magnesia, and silicon carbide are not attacked by magnesium at temperatures just above its melting point. Although quantitative data have not been obtained, beryllia, calcia, thoria, urania, and zirconia are also believed to be resistant to attack. Most other oxygen-containing compounds, such as quartz and silicates, are attacked by liquid magnesium at this low temperature.

Very little information is available on attack by liquid magnesium at temperatures above 850° C. Intergranular attack on steels becomes severe above this temperature, and if temperature variations exist, corrosion by mass

transfer is particularly severe. Tantalum, however, has shown good resistance. The other refractory metals have not been checked. Graphite also is resistant to attack, although, if of low porosity, it may be penetrated by magnesium. Magnesia and magnesium fluoride-bonded magnesia (10% MgF_2) are readily penetrated by magnesium. High-purity recrystallized alumina has shown good resistance up to 1,150° C.; however, blackening of the alumina occurs near the surface and is evidence of reaction or gradual penetration by magnesium. This reaction zone extended a depth of 2 mils into the alumina after 3 days' exposure at 1,150° C. and 4 mils after 6 days' exposure.

MOLTEN URANIUM-MAGNESIUM SYSTEM

To date, only three materials show resistance to attack by this system (temperature ~1,150° C.); high-purity recrystallized alumina, graphite, and tantalum. Of these, the most satisfactory is alumina. As the solubility of tantalum in uranium is about 0.3 wt. % at 1,150° C., failure of tantalum would ultimately occur. A drawback to the use of graphite is that reaction to give uranium carbide begins to be appreciable at this temperature. All these materials are wet. It may be of interest that on cooling, a thin layer of magnesium is present between the uranium phase and the crucible walls. It is not known whether or not this barrier is protective or whether it even exists when the phases are molten or is formed as a result of the prior solidification and shrinkage of the uranium.

Corrosion conditions are made less severe by the use of a low-melting alloy of uranium, such as the uranium-chromium eutectic melting at 860° C. No corrosion of tantalum by this uranium alloy–magnesium system at 900° C. has been evident. The reaction of uranium and graphite is also greatly diminished.

Materials compatible with magnesium and the magnesium-uranium system are summarized in Table 2.

Table 1.—Melting and Boiling Points of Metals in Magnesium Extraction Process

Metal	Melting point, ° C.	Boiling point, ° C.
Magnesium	650	1,106
Uranium	1,133	~3,900
Plutonium	660	3,240

Table 2.—Materials Suitable for Containing Molten Magnesium and the Molten Magnesium-Uranium System

Molten magnesium up to 800° C.	Molten magnesium 950° to 1,150° C.	Molten magnesium-uranium or Mg-U alloy systems
	Metals	
Cast iron Low-carbon steels High-chrome steels Tantalum, tungsten Titanium, molybdenum Chromium, niobium	Tantalum (Possibly titanium, tungsten, molybdenum, chromium, and niobium)	Tantalum
	Refractories	
Graphite, alumina Magnesia, silicon carbide Beryllia, calcia Urania, thoria Zirconia	Graphite Alumina	Graphite Alumina

PLUTONIUM EXTRACTION

The distribution coefficient of plutonium between molten uranium and magnesium at 1,150° C. is about 0.2 mole fraction of plutonium in magnesium per mole fraction of plutonium in uranium. This is equivalent to an extraction coefficient of about 2 on a weight basis. The distribution coefficient in laboratory single extractions has remained constant at this value for initial plutonium concentrations of up to 1 wt. % in uranium, which is the concentration range of interest. This distribution coefficient also holds for extraction of plutonium from a uranium-5-wt.-%-chromium alloy.

In static laboratory experiments the equilibrium distribution was approached very slowly, as long as 6 hr. being required. However, if the phases are agitated by mechanical or inductive mixing, equilibrium is achieved in a relatively short time, ½ hr. or less. Agitation of the phases therefore is regarded as essential.

The solubility of uranium in magnesium is about 0.16 wt. % at 1,150° C. The amount of uranium accompanying the plutonium will be dependent on the extraction scheme employed, for example, simple multiple batch or continuous countercurrent extraction. The effect of various extraction schemes on product purity and magnesium requirements is given in Table 3.

If plutonium is extracted from molten uranium, the operating temperature must be around 1,150° to 1,200° C. Since magnesium boils at 1,106° C., the extraction must be carried out under 1½ to 2 atm. pressure. To dispense with a pressure operation and also to reduce attack on container materials, one may add chromium to the uranium to reduce the melting point. The chromium-uranium eutectic composition (5-wt. % chromium), which has a melting point of ~860° C., is generally used.

While advantageous in lowering operating temperatures, the use of a uranium-alloying element is disadvantageous in that it provides an additional contaminant of the plutonium

Table 3.—Comparison of Various Magnesium Extraction Schemes

Bases: About 95% recovery of plutonium from 10 kg. of uranium.
Plutonium distribution coefficient (mole fraction basis) = 0.2
Solubility of uranium in magnesium = 0.16 wt. %
Equal weight extractions

Scheme	Number of extractions	Total wt. of magnesium required, kg.	Pu recovery, %	Product purity, %
Simple multiple batch	4	40	98	60
Countercurrent batch	4	10	97	85
Continuous countercurrent	3 stages	10	95	85
Sohxlet	...	40	95	60

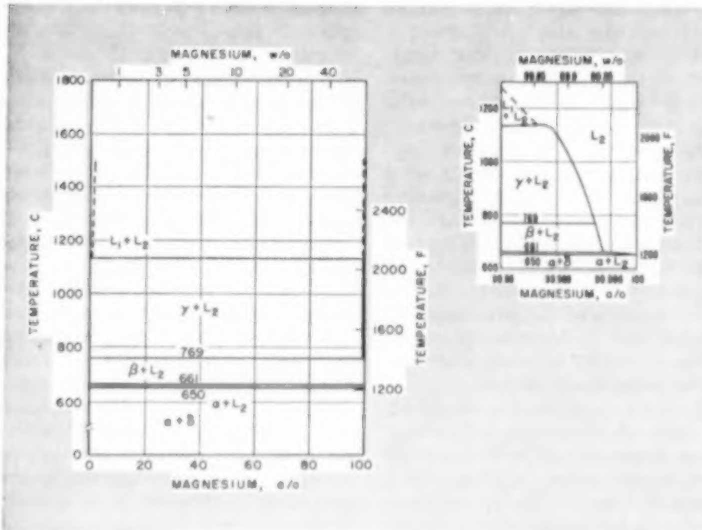


Fig. 2. The system uranium-magnesium.

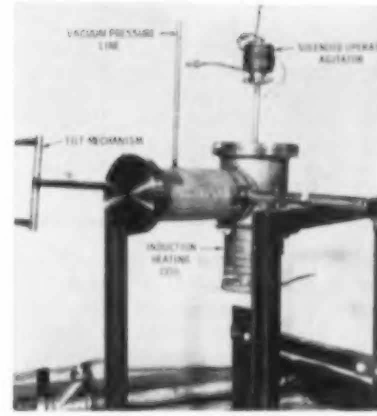


Fig. 4. Small-scale batch extraction unit.

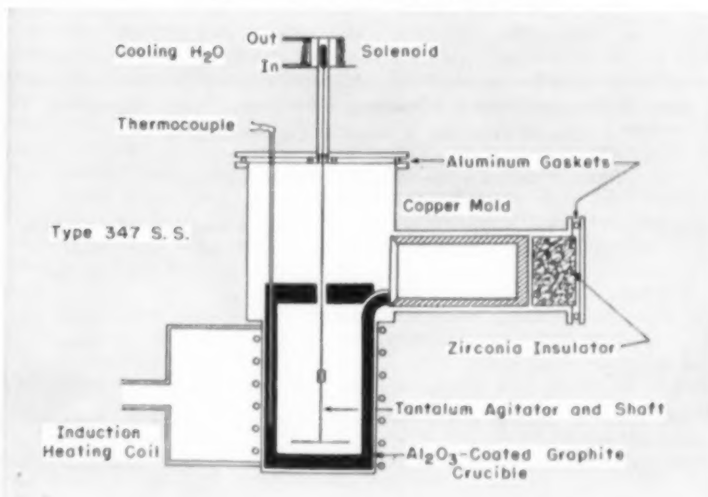


Fig. 3. Small-scale extraction unit.

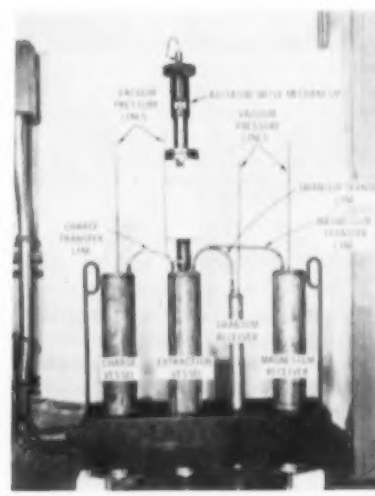


Fig. 6. Pilot plant scale magnesium extraction unit.

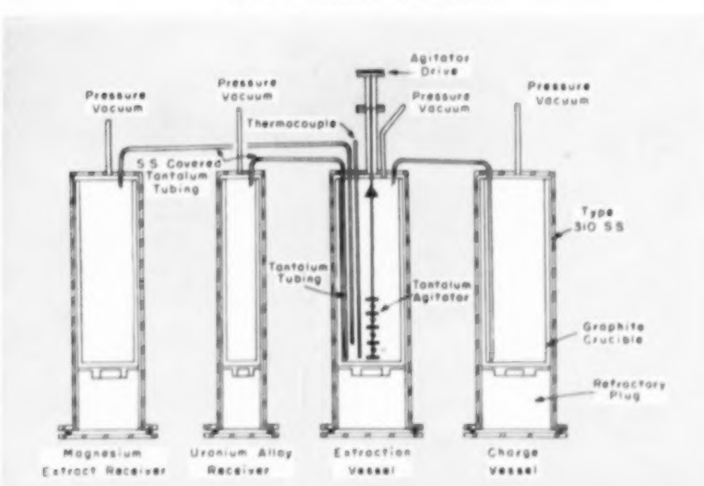


Fig. 5. Schematic flow diagram of five-kilogram scale magnesium extraction unit. (Unit is installed in large resistance furnace.)

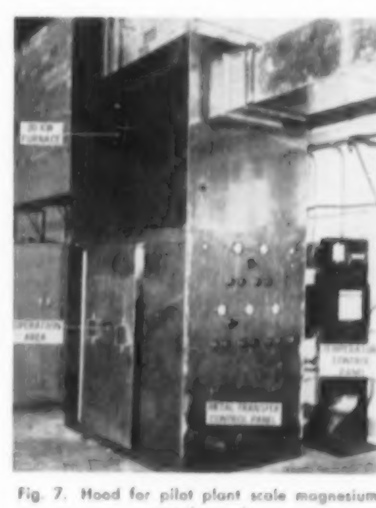


Fig. 7. Hood for pilot plant scale magnesium extraction unit.

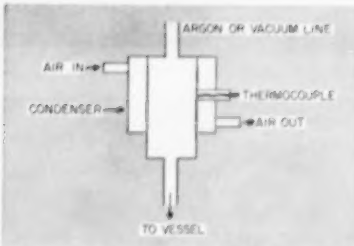


Fig. 8. Magnesium vapor trap.

product. The solubility of chromium in magnesium has been reported as 0.008 wt. %. Magnesium extractions of a uranium-5-%-chromium alloy at 950° C. have resulted in chromium concentrations of about 0.02 wt. % in magnesium. On the basis of this value the plutonium product from simple batch extractions would run about 8 wt. % chromium.

From the standpoint of product purity and magnesium economy, it would be advantageous to use a countercurrent extraction scheme; however, the present state of development is such that simple batch extraction is itself a considerable challenge, and to date only this scheme has been investigated.

EQUIPMENT DEVELOPMENT AND PERFORMANCE

A small-scale batch extraction unit (Figures 3 and 4) was constructed in order to make successive extractions of a uranium–1-wt.-%-plutonium-5-wt.-%-chromium alloy. The capacity of this unit is ½ kg. for each of the magnesium and uranium phases. The phases are mixed for ½ hr. in an alumina-coated graphite crucible by a reciprocating tantalum agitator. Separation of the phases is accomplished by solidifying the uranium and pouring off the magnesium phase.

Four successive ½-hr. batch magnesium extractions were made of a 500-g. charge of a uranium-chromium alloy (5-wt.-%-chromium) which initially contained 1 wt. % plutonium. Between 300 and 400 g. of magnesium was used for each contact. Slightly more than 85% of the plutonium was extracted in the magnesium phases (Table 4). The over-all plutonium material balance was 96%.

In these extractions the mole fraction ratio of plutonium in the magnesium phase to that in the uranium phase decreased from 0.185 to 0.046. Failure to achieve a distribution ratio of 0.2 may be due to several causes, for instance, (1) equilibrium was not achieved, or (2) inextractible plutonium compounds were formed. Further information on this point is being obtained.

It is noteworthy that spread of plutonium activity through equipment has been very slight. In those instances where a spill occurred as a result of crucible breakage, there has been virtually no contamination of the surface onto which the active metal poured. Little clean-up beyond removal of the spilled materials was required.

To provide experience in the handling of molten magnesium and uranium phases, a larger semiworks-scale extraction unit, capable of handling 5 kg. each of the magnesium and uranium phases, has been constructed. The system includes an extraction vessel, charge vessel, and receivers for the separated uranium and magnesium phases. (*See* Figures 5, 6, and 7.) The entire unit is positioned within a 20-kw. resistance furnace capable of maintaining temperatures of about

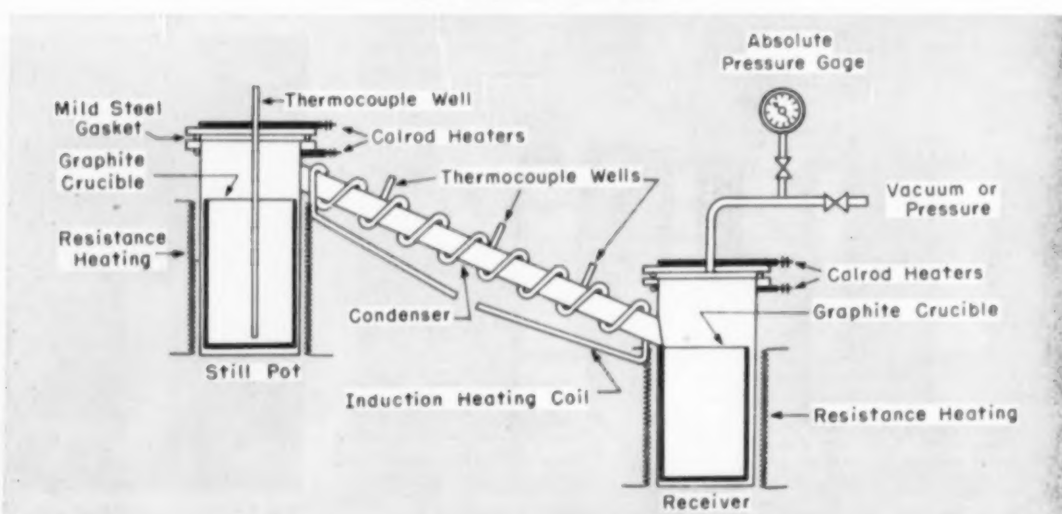
Table 4.—Successive Batch Extractions of Plutonium with Magnesium

Uranium alloy: 5-wt. % chromium, 1-wt. % plutonium
Charge: 500 g. of alloy, 5.17 g. of plutonium
Extraction time: ½ hr. for each extraction

Extraction No.	Wt. of Mg used, g.	Plutonium in extract: Wt., g.	Plutonium in extract: % of Available Pu ext.	Mole fraction ratio *
1	347	2.91	56.5	0.185
2	324	0.86	38.5	0.095
3	399	0.45	32.2	0.059
4	355	0.18	19.0	0.046
	Total	4.40		

* Mole fraction of plutonium in magnesium phase to that in uranium phase. At equilibrium the ratio should be 0.21.

Fig. 9. Magnesium distillation unit.



1,000° C. About 5 hr. is required to heat to 1,000° C. and approximately 10 hr. to cool to room temperature.

The phases are transferred from vessel to vessel by means of pressure and vacuum. There are pressure-equalizing lines between the extraction vessel and the magnesium and uranium receivers to prevent material transferring to the wrong vessel. All transfer lines are fabricated of tantalum and outside the vessel are clad with stainless steel to prevent oxidation of the tantalum. The phases are mechanically mixed with a tantalum stirrer rotating at 600 rev./min. The stirrer packing gland, located outside the furnace, is water cooled.

The operational sequence involves loading the charge vessel with the magnesium and uranium charges; degassing at 400° C. with a mechanical vacuum pump, after which an argon atmosphere is maintained in the equipment; heating to 1,000° C.; transferring the molten magnesium- and uranium-alloy phases to the extraction vessel by means of pressure; mixing the phases for ½ hr.; and finally transferring each phase to an individual receiver.

Initial experience with this unit has been gratifying. Under a pressure differential of 5 lb./sq.in. for magnesium and 18 for uranium, the phases transfer in a few seconds without difficulty.

In initial runs the heel remaining in the charge and extraction vessel froze to the tips of the transfer lines and prevented the removal of this crucible. To prevent this occurrence, a screw mechanism was incorporated into the bottom flanges of these vessels to provide a means of lowering and raising the crucible within the vessel.

Difficulty has been experienced with partial or complete plugging of the vacuum-pressure lines due to magnesium condensation. This is being remedied by the use of small vapor traps within the furnace, which are maintained at a temperature somewhat below the freezing point of magnesium by air cooling. (*See* Figure 8.) Any magnesium vapor diffusing into these lines is solidified. On discontinuance of cooling, the traps will heat to above the magnesium melting point, and any condensed magnesium will drain or may be blown back to the vessel.

Removing the ingots and heels from the graphite crucibles is also difficult. It is apparent that at the high temperatures used the liquid magnesium penetrates the porous walls of the graphite. "Graphitite" crucibles, graphite treated to provide a relatively nonporous surface, have been ordered and will be tested.

In this equipment an imperfect separation of the phases is effected. The quantity of uranium used is such that the interface is below the magnesium transfer line; consequently, a clean magnesium product is obtained, but any magnesium remaining in the extraction vessel is transferred with the uranium. In practice, this may not be serious as little plutonium would be present in the final uranium raffinate and magnesium heel. However, consideration is also being given to incorporating a phase-separation vessel.

Data will be forthcoming on successive batch extractions of plutonium-chromium-uranium alloys containing up to 1-wt. % plutonium.

In this first relatively large-scale extraction unit to be built and tested, transfer and handling of the molten phases have not proved to be difficult. Bolder designs of new extraction equipment are being developed on the basis of the experience obtained with this unit.

Magnesium Distillation

The object of the magnesium-distillation studies was to develop equipment for demonstrating distillation of magnesium and its condensation and collection as a liquid, since in process use it will be most convenient to handle the magnesium in the liquid state.

In order to reduce attack of molten magnesium on fabrication materials, the magnesium distillation is conducted under reduced pressure, the temperature selected being 725° C., corresponding to a magnesium vapor pressure of 10 mm. A condensing temperature of ~680° C., intermediate between the freezing point and the temperature of distillation, gives reasonable temperature differences for practical operation.

Fairly successful operation was achieved with the unit shown in Figure 9, in which the still pot and receiver were heated by resistance elements and the condenser was heated inductively by an 80-turn induction coil from a 15-kw. motor-generator unit. An induction coil was used, as it provides a method of removal of the heat of condensation by radiation to the coil and surroundings.

Fig. 10. Schematic flow diagram of magnesium distillation unit with sodium-cooled condenser.

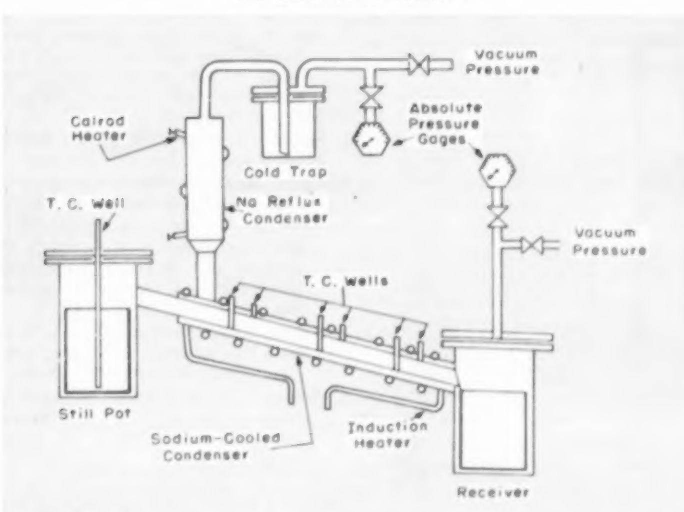
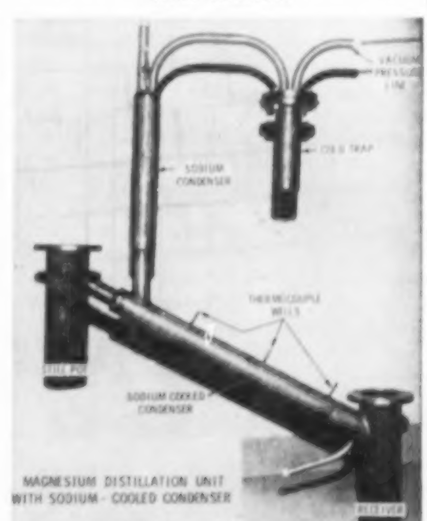


Fig. 11. Magnesium distillation unit with sodium-cooled condenser.



This unit was fabricated of type-347 stainless steel. Although this material is attacked by magnesium, it was used because of its resistance to air oxidation; however, attack by magnesium was apparently very slight. Graphite crucibles were used in the receiver and still pot, and mild steel gaskets were used between the flanges to provide a vacuum-tight unit.

The major difficulty with this unit was that large temperature gradients existed along the condenser. While it may have been possible to obtain a uniform temperature along the condenser by adjustment of spacing between coil turns, this was considered an unsatisfactory approach. Resistance heating was tried, but this was unsatisfactory because it was not possible to remove the latent heat of the condensing magnesium and so the condenser temperature would rise to that of the still pot. Consequently, it was decided to jacket the condenser and employ liquid sodium as a coolant. Two alternative cooling methods are possible: one is to circulate liquid sodium through the jacket and remove the heat of condensation in an external heat exchanger; the other is to use a static sodium system in which the pressure is adjusted to give a sodium boiling point of 670° to 680° C., which is about 60 mm. Hg. Heat of condensation boils the sodium, which is condensed in an air-cooled reflux condenser. (See Figures 10 and 11.) An induction coil is used to heat the sodium to 670° C. and to maintain it at this temperature. Close control of power input, whether from the induction coil or condensing magnesium, is not required as only the rate of sodium vaporization is affected. The static sodium system is also much simpler than a flowing system since it eliminates the need of a pump and complicated heat exchanger.

Performance of the sodium-cooled unit has been excellent in the four cold runs and one active run made. About 2 kg. of magnesium was distilled in each run. Temperatures along the condenser varied by only 10° or less, and the temperature of the condenser could be maintained at 670° to 680° C. with no difficulty.

One active run, involving 1,600 g. of magnesium and 3 g. of plutonium, has been made. Baffles were used in the still pot, as previous work showed them to be necessary to reduce plutonium entrainment to about 0.01%. For easy recovery of the plutonium, care was taken to prevent the still pot from running dry. This was done by fixing the still-pot thermocouple well about ½ in. above the bottom of the crucible, so that the thermocouple temperature would rise when the liquid level dropped below the thermocouple tip. A still-pot heel of 300 g. of magnesium resulted. The distillate appeared very clean and contained 0.5 mg. of plutonium, which resulted in a decontamination factor of 6×10^3 or 6,000 for the distilled magnesium.

AUXILIARY COMPONENTS

Successful application of magnesium extraction requires development of several auxiliary-equipment components, including valves, liquid-level indicators, samplers, and perhaps pumps. Development and testing of these items is in an early stage. A simple freeze valve of the type shown in Figure 12 has worked successfully.

The sampling technique envisaged for the future is the use of a Vycor or graphite tube which will be lowered through a pressure seal under argon pressure until the proper level is reached, when the tube will be put under vacuum and the sample withdrawn. This technique is used in sampling molten uranium and steel at much higher temperatures.

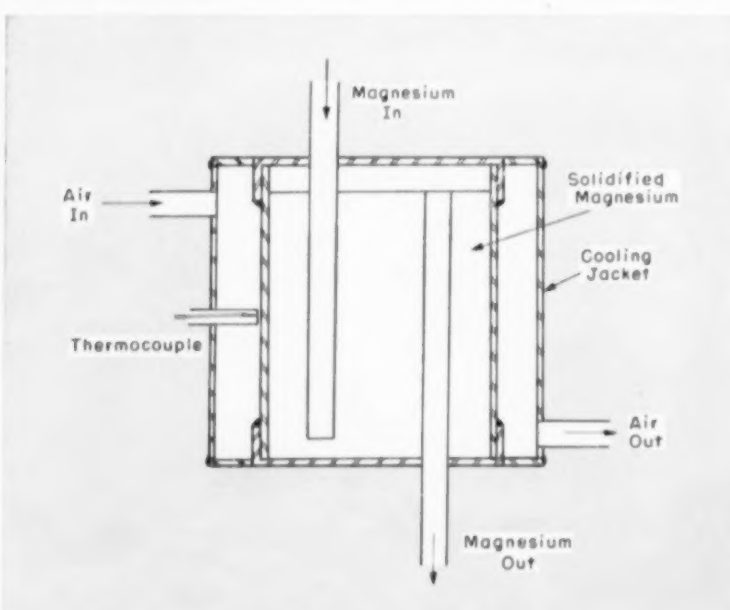


Fig. 12. Magnesium freeze valve.

Summary

The principles of a magnesium-extraction process have been described. Considerable work remains in the development of a complete system of remotely operable equipment. Principal problems are those of materials of construction and materials handling. One of the problems which will receive considerable emphasis in future work is the handling of the concentrated plutonium product. Quantitative transfer of the plutonium from a concentrated magnesium solution back into a uranium system must be demonstrated. Although not all the problems have been solved, the process is considered a promising method for recovering plutonium in metal form directly from reactor fuel and blanket materials.

Acknowledgment

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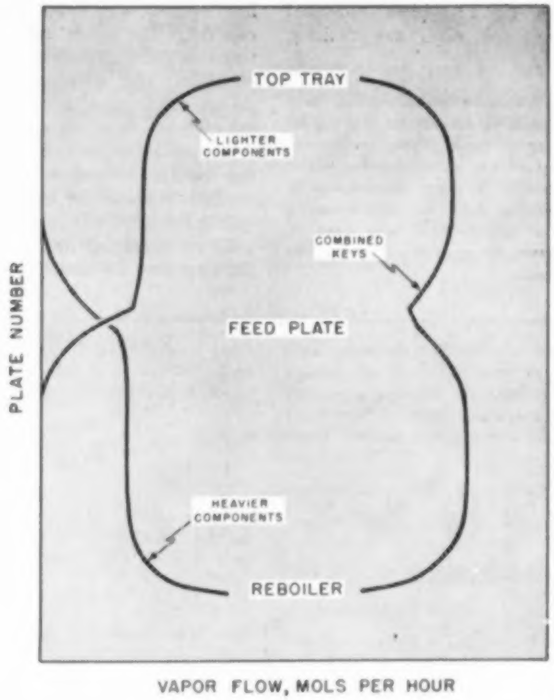

Fig. 1. Vapor flows in a typical tower.

a rigorous graphical method for calculating MULTICOMPONENT DISTILLATIONS

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Tray requirements for most multicomponent distillation towers can be determined rigorously only by stepwise tray-to-tray calculations up from the bottom and down from the top. Tray-to-tray calculations are tedious, and trial-and-error matching at the feed tray is difficult and time-consuming. A method is here presented that minimizes the tray-to-tray calculations and avoids the matching problem. Simple equations are also presented for approximating the splits of materials other than the key components.

Tray requirements are determined by a modification of an approximate method described earlier (*3*). As in original method, the multicomponent system is reduced to an equivalent binary, but the approximations of the original method are eliminated. Answers obtained by the two methods are usually close, but they may differ appreciably when the feed stock contains large amounts of materials with volatilities close to those of the keys, particularly if the reflux ratio is near the minimum.

Basis for Tray Calculations

Most distillations are characterized by the way that two "key" materials split between the overhead and bottoms products. How the keys split depends only on their relative volatilities on each tray and on the amounts of the combined keys in the liquid and vapor streams. Thus, an exact solution can be obtained by treating a multicomponent system as a binary of the keys, provided that the amounts of the keys in the vapor and liquid streams and their relative volatilities on each tray can be established.

Because vapor and liquid rates are related by material balances, establishing one establishes the other. How vapor rates change in a typical tower is illustrated in Figure 1. The rates of the components lighter than the keys drop off sharply at the top of the tower, approach constant values in the intermediate zone of the rectifying section, dip slightly just above the feed tray, and disappear rapidly below it. The components heavier than the keys drop off sharply at the bottom of the tower, approach constant values in the intermediate zone of the stripping section, dip slightly just below the feed inlet, and disappear rapidly above it. The combined keys reach maximum concentrations in the intermediate zones of the rectifying and stripping sections.

The reasons for the shape of each curve can be deduced from mathematical relationships developed by Jenny (*4*). Jenny showed that the amount of each component lighter than the keys cannot drop below a limiting value in the rectifying vapors so long as little material heavier than the keys is present. Similarly, the amount of a component heavier than the keys cannot fall below a limiting value in the stripping vapors so long as little material lighter than the keys is present. At the top of the tower, then, the light materials approach their limiting, minimal flow rates; by material balance, the combined keys must approach their maximum flow rate. As the feed tray is approached, heavy components become appreciable. By material balance, the other components must be reduced. In view of this pattern, the combined keys in the rectifying vapors

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cannot exceed the amount obtained by subtracting from the total vapor the limiting flow rates for the lighter components, as calculated from Jenny's equations. The lighter components may dip below these limiting flow rates near the feed tray, but the dips are more than offset by the heavy components that cause them. Parallel arguments apply to the stripping section.

The present method first establishes the limiting flows for the combined keys.* The operating lines calculated from these flow rates are limiting lines, below which no operating line can fall. The operating lines for the trays in the intermediate zones of the rectifying and stripping sections approach the limiting lines. Tray-to-tray calculations are made to determine operating lines for individual trays at the top and bottom of the tower and on both sides of the feed inlet. These calculations are continued in each zone until an operating line approaches the limiting line as closely as is desired.

* To avoid trial-and-error calculations, Jenny made the simplifying assumptions that d/l for the heavy key in the rectifying section and b/v' for the light key in the stripping section are small relative to unity. Because the inaccuracy resulting from his assumptions is negligible, his simplifications have been retained. However, the exact equations could be used if desired.

Procedure

In many fractionation problems, the molal overflows of liquid from tray to tray in the rectifying section are constant, the same is true of the stripping section, and relative volatilities are constant. The procedure for solution of such problems follows.

1. Assume a reflux ratio and calculate the moles of liquid and vapor flowing in the two sections of the tower.
2. Calculate the limiting flow rates for the components lighter and heavier than the keys* by the following modifications of Jenny's equations:

(a). for each lighter component in the rectifying section,

$$l = \frac{a_{hk}d}{a - a_{hk}} \quad ; \; v = l + d$$

(b). for each heavier component in the stripping section,

$$v' = \frac{ab}{a_{lk} - a} \quad ; \; l' = v' + b$$

3. Determine the limiting flows of the keys by subtracting the flow rates calculated in step (2) from the total liquid and vapor flow rates, to obtain L_e, V_e, L_e', and V_e'.
4. Construct a McCabe-Thiele diagram (5) for the keys. Draw the limiting operating lines, with slopes of L_e/V_e and L_e'/V_e', but do not "step off" the tray requirements.
5. Estimate the slopes of the operating lines for the feed tray and the tray above to determine whether the operating lines for the trays near the feed will deviate significantly from the limiting operating lines. The operating lines for these trays will not lie above lines having slopes defined by:

$$\frac{L_e' - (\Sigma f_l + \Sigma l)}{V_e' - (\Sigma f_l + \Sigma l)}$$

for the feed tray, and

$$\frac{L_e - (\Sigma f_v + \Sigma v')}{V_e - (\Sigma f_v + \Sigma v')}$$

for the tray above the feed.

In most cases, these lines are close enough to the limiting operating lines that their use would have only a slight effect on tray requirements. In such cases, no adjustments at the feed tray are warranted, and the next three steps may be omitted.

6. Determine the compositions of the vapor from the feed tray and the liquid from the tray above if adjustments at the feed tray are required. Assume temperatures for these trays, calculate the compositions, and check them by a dew-point calculation on the feed-tray vapor and a bubble-point calculation on the liquid from the tray above.

For the first trial, assume temperatures such that the following flow rates (previously calculated) apply:

	v_f'	l_{f+1}
Lighter components	$f_l + l$	l
Key components	by difference	by difference
Heavier components	v'	$f_v + v'$

Treat the key components as a single component (with a volatility estimated from the composition at which the limiting operating lines intersect), and determine the dew point of the feed-tray vapor and the bubble point of the liquid from the tray above. From Jenny's equations, $(K_{lk})_f$ should equal L'/V' and $(K_{hk})_{f+1}$ should equal L/V. A close check will usually be obtained. If a check is not obtained, assume new temperatures and repeat the calculations. For the second (and subsequent) trials, the amount of each heavier material in the feed-tray vapor is calculated from

$$v_f' = \frac{b}{\dfrac{L'}{KV'} - 1}$$

and the amount of each lighter material in the liquid from the tray above the feed is calculated from

$$l_{f+1} = \frac{d}{\dfrac{KV}{L} - 1}$$

7. Determine the slope of the operating line for each successive tray above the feed inlet until an operating line approximates the limiting operating line. To obtain the slopes, calculate up from the feed inlet tray to tray, holding the lighter materials at the limiting flows calculated in step (2),* and treating the combined keys as a single component. (The limiting amounts of the lighter materials are most conveniently taken into account by using L_e and V_e in place of L and V and omitting the lighter materials from the calculations.) Obtain the slope of each operating line from the l/v for the combined keys, where l refers to the tray in question and v refers to the next lower tray.
8. Similarly determine the slopes of the operating lines for the trays immediately below the feed inlet, holding the amounts of the heavier components at the limiting flows calculated in step (2),* and treating the combined keys as a single component. Plot the operating line for each tray on the McCabe-Thiele diagram.
9. Calculate the steps at the top of the tower tray to tray, determine the binary liquid and vapor concentrations for each step, and plot them on the McCabe-Thiele diagram. Continue the calculation until the steps are defined approximately by the limiting operating line.
10. Calculate the steps at the bottom in a similar manner.
11. Starting with the intersection of the operating lines for the feed tray and the tray above, step off the trays in either

* Key components are the components which define the separation. As discussed previously (3) "effective keys" are used when other materials have volatilities close to those of the actual keys. Effective keys are obtained by plotting the d/b ratios for the key components against a on log paper (rather than semilog paper, as recommended earlier), drawing a straight line through the points and reading the d/b ratios for the other components. (The splits so obtained are very close to the true splits for sharp separations, and are less close for sloppy separations (3). It is the authors' practice to include in the effective light key lighter components whose d/b ratios are less than 10 $(d/b)_{lk}$, and to include in the effective heavy key heavier components whose d/b ratios are greater than 0.1$(d/b)_{hk}$. Distributed components are included in the effective light key if their d/b ratios are greater than 1, in the effective heavy key if their d/b ratios are less than 1.

* In calculating up from the feed tray, the dips in the flow rates of the components lighter than the keys are neglected, because these flow rates rapidly approach their "limiting" values. For the same reason, the dips in the flow rates of the heavier components are neglected below the feed.

direction, using the appropriate operating line for each step. Continue until the terminal compositions of steps (9) and (10) are reached.

12. Count the number of equilibrium steps to obtain the trays required at the assumed reflux ratio.

The method is not limited to systems that involve constant relative volatilities and constant molal overflows. Variations in relative volatility are easily taken into account (*3*). The overflows at either end of the tower are readily calculated by heat balances in conjunction with tray-to-tray calculations. The overflow at an intermediate point can be estimated as illustrated below for the rectifying section.

1. **Define the intermediate point by the binary composition of the keys.**
2. **Assume that the materials lighter than the keys are at their limiting values.**
3. **Assume the amounts of the keys and calculate the bubble point of the liquid.**
4. **Check the amounts assumed for the keys by a heat balance calculation.**

The operating line so determined is plotted on the McCabe-Thiele diagram at the proper composition. A few such calculations determine the limiting operating line for the rectifying section as a function of composition. The limiting operating line is determined for the stripping section in a similar manner.

Example

Murdock and Holland have described (*6*) a separation that provides a severe test of the procedure described herein, inasmuch as non-key materials with volatilities close to those of the keys comprise 85 per cent of the feed, and a reflux ratio close to the minimum is used. The separation is defined by the following quantities:

Component	α	f	d	b
A	4.0	59	59.00	.....
B	2.0	10	9.52	0.48
C	1.0	5	0.24	4.76
D	0.5	26	.....	26.00
			68.76	31.24

Liquid and vapor quantities calculated from the data given in the example are: $L = 35.2$, $V = 104.0$, $L' = 135.2$, $V' = 104.0$

To reduce the system to an approximate binary of the keys, the limiting flows are calculated.

For the lighter component A:

$$l = \frac{\alpha_{hk} d}{\alpha - \alpha_{hk}} = \frac{1 \times 59}{4 - 1} = 19.7$$

$$v = l + d = 19.7 + 59 = 78.7$$

For the heavier component D:

FIRST TRIAL

FEED TRAY

Assume: $K_B = L'/V' = 1.30$

Then v_f' for $D = 8.7$

Dew-point of V_f'

Component	v_f'	v_f'/α
A	78.7	19.7
B+C	16.6	9.0
D	8.7	17.4
	104.0	46.1

Dew-point K_B:

$$\frac{46.1}{104.0} \times 2.0 = 0.89$$

TRAY ABOVE FEED

Assume: $K_t = L/V = 0.34$

Then l_{f+1} for $A = 19.7$

Bubble-point of L_{f+1}

Component	l_{f+1}	αl_{f+1}
A	19.7	78.8
B+C	6.8	12.7
D	8.7	4.4
	35.2	95.9

Bubble-point K_t:

$$\frac{35.2}{95.9} \times 1 = 0.37$$

SECOND TRIAL

Assume: $K_B = 0.80$

Component	K	L'/KV'	b	v_f'
D	0.20	6.50	26	4.7

Dew-point of V_f'

Component	v_f'	v_f'/α
A	76.6	19.2
B+C	22.7	12.2
D	4.7	9.4
	104.0	40.8

Dew-point K_B:

$$\frac{40.8}{104.0} \times 2.0 = 0.78$$

Assume: $K_t = 0.37$

Component	K	KV/L	d	l_{f+1}
A	1.48	4.35	59	17.6

Bubble-point of l_{f+1}

Component	l_{f+1}	αl_{f+1}
A	17.6	70.4
B+C	12.9	24.0
D	4.7	2.4
	35.2	96.8

Bubble-point K_t:

$$\frac{35.2}{96.8} \times 1 = 0.36$$

Fig. 3. Trial-and-error calculations to determine compositions at the feed inlet.

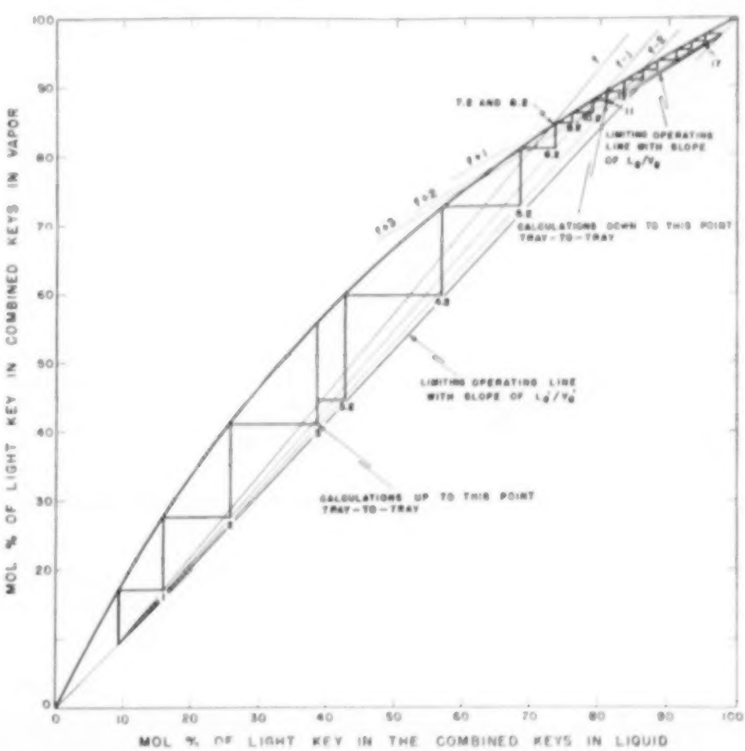

Fig. 2. Graphical solution for the example problem.

Table A.

Component	d	α	l_{f+1}	αl_{f+1}	v_{f+2}	l_{f+2}	αl_{f+2}	v_{f+3}	l_{f+3}
B & C	9.8	1.86	10.8	20.0	22.6	12.8	23.8	23.9	14.1
D	0.0	0.50	4.7	2.4	2.7	2.7	1.4	1.4	1.4
			15.5	22.4	25.3	15.5	25.2	25.3	15.5
$\frac{l}{v}$ (for B & C)			0.53			0.57			0.59

$$v' = \frac{ab}{\alpha_{lk} - \alpha} = \frac{0.5 \times 26}{2.0 - 0.5} = 8.7$$

$$l' = v' + b = 8.7 + 26 = 34.7$$

For the combined keys:

$$L_e = 35.2 - 19.7 = 15.5$$

$$L_e' = 135.2 - 34.7 = 100.5$$

$$V_e = 104.0 - 78.7 = 25.3$$

$$V_e' = 104.0 - 8.7 = 95.3$$

The McCabe-Thiele diagram for the keys is then constructed. The upper limiting operating line has the slope of L_e/V_e, or 0.615. The lower limiting operating line has the slope L_e'/V_e', or 1.055. For locating the lines, the composition of the overhead product equals $9.52/(9.52+0.24)$ or 0.975 mole fraction of the light key, and the composition of the bottoms product equals $0.48/(0.48+4.76)$, or 0.091 mole fraction of the light key.

Preliminary calculations (step 5) indicate that the heavy ends in the rectifying section and the light ends in the stripping section will have significant effects at the feed tray. Accordingly, the compositions of the vapor from the feed tray and the liquid from the tray above are approximated by trial and error. Because all of the feed enters the tower as liquid in this example, l_{f+1} for the heavier component (D) equals v_f', and v_f' for the lighter component (A) equals $l_{f+1} + f$. The approximate composition of the combined keys is determined from the intersection of the limiting operating lines in Figure 2 at 0.86 mole fraction of component B. The relative volatility of the combined keys is taken as $(0.86 \times 2) + (0.14 \times 1) = 1.86$. The trial-and-error calculations are shown in Figure 3.

To determine the slopes of the operating lines for the trays immediately above the feed inlet, tray-to-tray calculations are made upward from the tray above the feed. (See Table A.)

The operating line for each tray is plotted on the McCabe-Thiele diagram. By inspection, the operating line for tray $f + 3$ is close enough to the limiting operating line that no further upward calculations are warranted. Operating lines for the trays below the feed inlet are determined by similar calculations, as shown in Table B.

Again, by inspection of the plotted lines, further calculations are not warranted.

The steps at each end of the column are calculated tray to tray and the binary compositions so obtained are plotted on the McCabe-Thiele diagram (Figure 2). The intermediate trays are then stepped off. In the example, the operating lines for the feed tray and the tray above intersect on the equilibrium line. This means that there are two theoretical trays at the point of intersection: namely, the feed tray and the tray above. The total tray requirements are 17.0, with 7.2 of them in the stripping section.

Discussion

For comparison, the tray requirements for this separation have been calculated by a careful tray-to-tray calculation. To make the comparison direct, a second graphical solution was made, in which the shift from the rectifying to the stripping section was made at the same composition as in the tray-to-tray calculation. The calculated tray requirements are:

	Stripping	Rectifying	Total
Graphically	7.7	9.3	17.0
Tray to tray	7.8	9.0	16.8*

The agreement is well within the requirements of engineering accuracy. The reason for the close agreement may be seen from Figure 4. The tray-to-tray calculations are nearly duplicated throughout the tower.

The second graphical solution is interesting in that it shows reverse fractionation of the keys at the feed tray (see Figure 5). This effect, which has been described previously in conjunction with operations at minimum reflux (*1, 2*), results from the large difference between the slopes of the binary operating lines for the feed tray and the next lower tray.

Implicit in the method is the assumption that the non-key components closely approach their limiting values in the rectifying and stripping sections. Their failure to do so might introduce appreciable errors in a case where the operating line for the feed tray or the tray above deviates considerably from the limiting operating line. In such a case, the calculations from the top and bottom of the tower should be carried far enough to ensure that the limiting values for the non-keys are approached closely.

Splits of Non-key Components

Most distillations are characterized sufficiently by the splits of the key components. In some cases, however, the exact splits of the non-key components are desired. Close approximations can usually be obtained from simple equations:

For each component heavier than the keys, when the overhead product is taken off as liquid,

$$\left(\frac{l_{f+1}}{d}\right)_D = \alpha_{CD}^n \left[1 - \frac{\alpha_{CD} - 1}{\alpha_{CD}\left(\frac{l_1}{d} + 1\right)_C}\right]\left(\frac{l_{f+1}}{d}\right)_C \tag{1}$$

For each component heavier than the keys, when the overhead product is taken off as vapor,

Table B.

Component	b	α	v_f'	v_f'/α	l_f'	v'_{f-1}	v'_{f-1}/α	l'_{f-1}	v'_{f-2}	v'_{f-2}/α	l'_{f-2}
A	0.0	4.00	76.6	19.2	66.0	66.0	16.5	51.7	51.7	12.9	35.6
B & C	5.2	1.86	18.7	10.0	34.5	29.3	15.8	48.8	43.6	23.4	64.9
			95.3	29.2	100.5	95.3	32.3	100.5	95.3	36.3	100.5
$\frac{l'}{v'}$ (for B & C)					1.18			1.12			1.09

* Murdock and Holland report 16.1. The difference may result from small differences in the liquid and vapor rates employed; Murdock and Holland did not report the actual numbers they used.

$$\left(\frac{l_{f+1}}{d}\right)_D = \alpha_{CD}^{n+1}\left[1-\frac{\alpha_{CD}-1}{\alpha_{CD}\left(\frac{l_0}{d}+1\right)_C}\right]\left(\frac{l_{f+1}}{d}\right)_C \tag{2}$$

For each component lighter than the keys in either case;

$$\left(\frac{v_f'}{b}\right)_A = \alpha_{AB}^{m+1}\left[1-\frac{\alpha_{AB}-1}{\alpha_{AB}\left(\frac{v_r}{b}+1\right)_B}\right]\left(\frac{v_f'}{b}\right)_B \tag{3}$$

Except for d_D for the heavier components and b_A for the lighter components, the values for all terms are readily obtained from the tray calculations. The equations are based on constant relative volatilities. If relative volatilities differ, the use of average figures is recommended.

DEVELOPMENT OF EQUATIONS

The following derivation applies to the rectifying section when the overhead product is totally condensed.

By component material balance

$$v_n = l_{n-1} + d \tag{4}$$

By definition

$$v_n = \frac{K_n V_n}{L_n} l_n \tag{5}$$

Combining (4) and (5)

$$l_n = \frac{L_n}{K_n V_n}(l_{n-1} + d) \tag{6}$$

Rearranging (6)

$$\frac{l_n}{d} = \frac{L_n}{K_n V_n}\left(\frac{l_{n-1}}{d} + 1\right) \tag{7}$$

Writing Equation (7) for components D and C

$$\frac{\left(\frac{l_n}{d}\right)_D}{\left(\frac{l_n}{d}\right)_C} = \frac{\left(\frac{L_n}{K_n V_n}\right)_D\left(\frac{l_{n-1}}{d}+1\right)_D}{\left(\frac{L_n}{K_n V_n}\right)_C\left(\frac{l_{n-1}}{d}+1\right)_C} = \alpha_{CD}\frac{\left(\frac{l_{n-1}}{d}+1\right)_D}{\left(\frac{l_{n-1}}{d}+1\right)_C} \tag{8}$$

For $n = 1$

$$\frac{\left(\frac{l_1}{d}\right)_D}{\left(\frac{l_1}{d}\right)_C} = \alpha_{CD}\frac{\left(\frac{l_0}{d}+1\right)_D}{\left(\frac{l_0}{d}+1\right)_C} = \alpha_{CD} \tag{9}$$

For $n = 2$ Equation (8) becomes

$$\frac{\left(\frac{l_2}{d}\right)_D}{\left(\frac{l_2}{d}\right)_C} = \alpha_{CD}\frac{\left(\frac{l_1}{d}+1\right)_D}{\left(\frac{l_1}{d}+1\right)_C} = \alpha_{CD}\frac{\left(\frac{l_1}{d}\right)_D+1}{\left(\frac{l_1}{d}+1\right)_C} \tag{10}$$

Substituting for $(l_1/d)_D$ its value from Equation (9)

$$\frac{\left(\frac{l_2}{d}\right)_D}{\left(\frac{l_2}{d}\right)_C} = \alpha_{CD}\frac{\alpha_{CD}\left(\frac{l_1}{d}\right)_C+1}{\left(\frac{l_1}{d}+1\right)_C} \tag{11}$$

Rearranging Equation (11)

$$\frac{\left(\frac{l_2}{d}\right)_D}{\left(\frac{l_2}{d}\right)_C} = \alpha_{CD}^2\left[1-\frac{\alpha_{CD}-1}{\alpha_{CD}\left(\frac{l_1}{d}+1\right)_C}\right] \tag{12}$$

For $n = 3$ Equation (8) becomes

$$\frac{\left(\frac{l_3}{d}\right)_D}{\left(\frac{l_3}{d}\right)_C} = \alpha_{CD}\frac{\left(\frac{l_2}{d}+1\right)_D}{\left(\frac{l_2}{d}+1\right)_C} \tag{13}$$

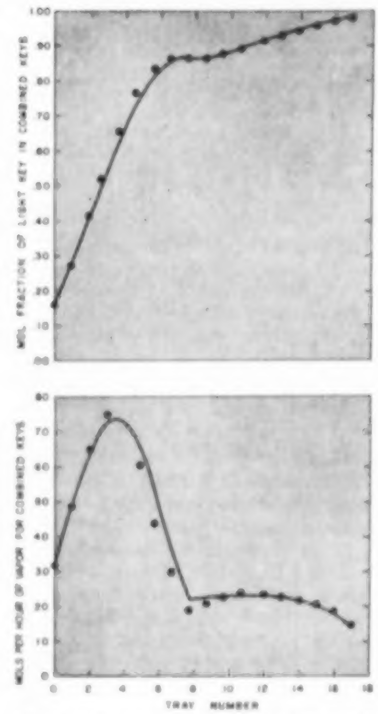

Fig. 4. Comparison of graphical solution with rigorous tray-to-tray calculation. Lines represent tray-to-tray calculations; points are from graphical solution.

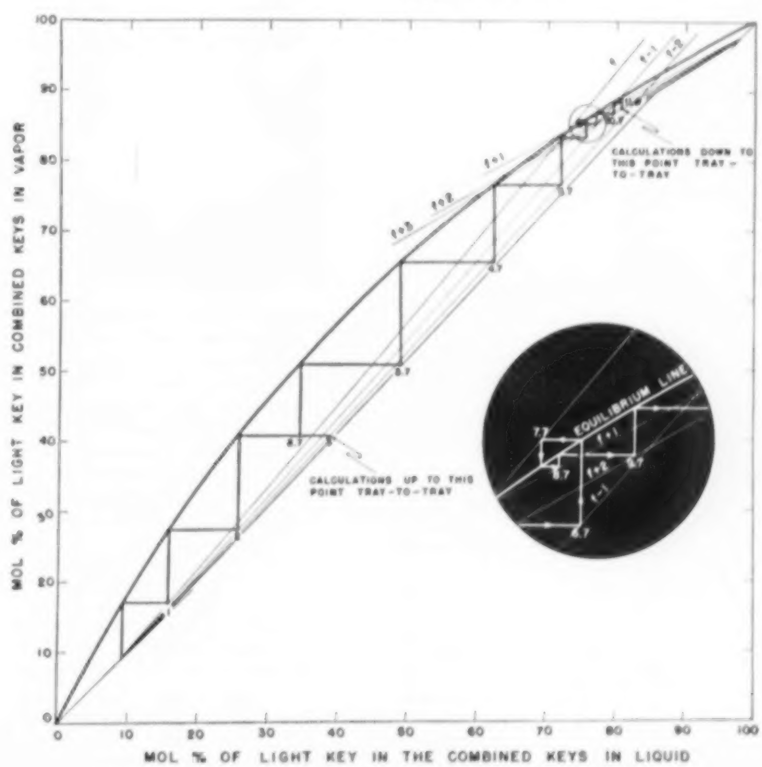

Fig. 5. Graphical solution for direct comparisons with tray-to-tray solution.

For the heavy key and heavier materials, (l_2/d) is usually much larger than unity. Substituting (l_2/d) for $(l_2/d+1)$ in Equation (13) and combining it with Equation (12)

$$\left(\frac{l_3}{d}\right)_D = \alpha^{j}_{CD}\left[1-\frac{\alpha_{CD}-1}{\alpha_{CD}\left(\frac{l_1}{d}+1\right)_C}\right]\left(\frac{l_3}{d}\right)_C \tag{14}$$

The general equation for each heavier material may be written

$$\left(\frac{l_{f+1}}{d}\right)_D = \alpha^{n}_{CD}\left[1-\frac{\alpha_{CD}-1}{\alpha_{CD}\left(\frac{l_1}{d}+1\right)_C}\right]\left(\frac{l_{f+1}}{d}\right)_C \tag{15}$$

If the overhead product is taken off the reflux drum as vapor, the general equation becomes

$$\left(\frac{l_{f+1}}{d}\right)_D = \alpha^{n+1}_{CD}\left[1-\frac{\alpha_{CD}-1}{\alpha_{CD}\left(\frac{l_0}{d}+1\right)_C}\right]\left(\frac{l_{f+1}}{d}\right)_C \tag{16}$$

If component C is taken as the heavy key component, the values for all of the terms in Equations (15) or (16) except d_D are available from the calculations of tray requirements. Thus, d_D can be obtained directly.

A similar derivation gives the equation for each light material in the stripping section:

$$\left(\frac{v_f'}{b}\right)_A = \alpha^{m+1}_{AB}\left[1-\frac{\alpha_{AB}-1}{\alpha_{AB}\left(\frac{v_r}{b}+1\right)_B}\right]\left(\frac{v_f'}{b}\right)_B \tag{17}$$

If component B is taken as the light key, the values for all of the terms, except b_A, are available from the calculations of tray requirements, and b_A can be obtained directly.

Example

From the calculations used in solving the example problem for determining tray requirements, the following values are readily obtained:

$$(l_{f+1})_D = 4.7$$
$$(l_1/d)_C = 1.79$$
$$(l_{f+1}/d)_C = \frac{0.27 \times 10.8}{0.24} = 12.2$$
$$(v_f')_A = 76.6$$
$$(v_r'/b)_B = 11.1$$
$$(v_f/b)_B = \frac{0.73 \times 18.7}{0.48} = 28.4$$

The splits of the non-key materials calculated from Equations (1) and (3) by use of these values compare with tray-to-tray calculations as follows:

Comp.	This method		Tray to tray	
	d	b	d	b
A	58.9933	0.0067	58.9940	0.0060
D	0.0007	25.9993	0.0026	25.9974

Excellent agreement is obtained for the light component; only fair agreement for the heavy component.

DISCUSSION

Close approximations will be obtained by this method in all cases in which l_1 or l_2 of the heavy key is large relative to d, and v_1 of the light key is large relative to b. In the example cited, v_1/b for the light key equals 27, and a close approximation of the split of the lighter component is obtained. On the other hand, the l_2/d for the heavy key equals only 3, and only a fair approximation is obtained for the heavier component. In most cases, however, this approximation would be close enough.

The usual practice in distillation calculations is to use the same tray efficiencies for all components, as in the present example. However, tray efficiencies may differ for the several components (7). Such differences can be accounted for by use of the appropriate values for n and m in Equations (1), (2), and (3).

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Presented at A.I.Ch.E. meeting, Boston, Massachusetts.

Notation

- b = moles/hr. of a component in the bottoms product
- d = moles/hr. of a component in the net overhead product
- f = moles/hr. of a component in the feed
- f_L = moles/hr. of a component lighter than the keys in the feed as liquid
- f_v = moles/hr. of a component heavier than the keys in the feed as vapor
- K = vapor-liquid equilibrium ratio
- K_{hk} = vapor-liquid equilibrium ratio of the heavy key
- K_{lk} = vapor-liquid equilibrium ratio of the light key
- l = moles/hr. of a component in the liquid from a rectifying tray
- l' = moles/hr. of a component in the liquid from a stripping tray
- $\underline{l}$ = limit moles/hr. of a light component in the liquid from a rectifying tray
- $\underline{l}'$ = limit moles/hr. of a heavy component in the liquid from a stripping tray
- L = moles/hr. of liquid falling from a rectifying tray
- L' = moles/hr. of liquid falling from a stripping tray
- L_o = limit moles/hr. of combined keys in rectifying liquid = $L - \Sigma \underline{l}$
- L_o' = limit moles/hr. of combined keys in stripping liquid = $L' - \Sigma \underline{l}'$
- v = moles/hr. of a component in the vapor from a rectifying tray
- v' = moles/hr. of a component in the vapor from a stripping tray
- $\underline{v}$ = limit moles/hr. of a light component in the vapor from a rectifying tray
- $\underline{v}'$ = limit moles/hr. of a heavy component in the vapor from a stripping tray
- v_r = moles/hr. of a component in the reboiler vapors
- V = moles/hr. of vapor rising from a rectifying tray
- V' = moles/hr. of vapor rising from a stripping tray
- V_o = limit moles/hr. of combined keys in rectifying vapor = $V - \Sigma \underline{v}$
- V_o' = limit moles/hr. of combined keys in stripping vapor = $V' - \Sigma \underline{v}'$
- α = relative volatility
- α_{AB} = volatility of A relative to B
- α_{CD} = volatility of C relative to D
- α_{hk} = relative volatility of the heavy key
- α_{lk} = relative volatility of the light key

Subscripts

- A = component lighter than the keys
- B = light key component
- C = heavy key component
- D = component heavier than the keys
- f = feed tray
- $f+1$, $f+2$, etc. = trays above feed tray
- $f-1$, $f-2$, etc. = trays below feed tray
- m = stripping tray, numbered from the bottom
- $m+1$ = tray above tray m
- n = rectifying tray, numbered from top
- $n+1$ = tray below tray n
- 1, 2, 3 = tray numbered from top of the rectifying section, or from the bottom of the stripping section

considerations for selection of LIQUID METAL PUMPS

The design and development of large-scale, liquid-metal circulating pumps such as would be suited to application in nuclear power plants have been investigated. Fluid dynamic problems—cavitation and erosion damage to the structural components at the high relative velocities obtained in the pump impeller—were the particular concern of the authors of the accompanying article.

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Many of the presently proposed and projected nuclear power plants utilize a liquid metal as either a primary or secondary coolant or perhaps as a fuel carrier as in the homogeneous reactor. In all these cases, one or more liquid-metal circulating pumps are required.

The liquid metals may be of several sorts, the most prominent at the present time being, on the one hand, sodium, potassium, and their alloys, and on the other, bismuth and its alloys.

Pump inlet pressures are restricted by the added complexities of the pump design for increased pressure and by the penalties throughout the entire system caused by an increase of pressure, the latter being important because of the high temperatures, large pipes, and expensive materials. It is also important where weight is a factor.

It is obvious then that in many cases the restricting factor in the pump design will be cavitation * and/or high impeller velocity. The former will necessitate pumps of unduly large size, cost, and weight and the latter a different type of design, such as the use of multistage units. Due to the special requirements of the application, even under ideal conditions the pump is an extremely expensive and weighty item.

Over the years, empirical limits have been established for water pumps with respect to cavitation performance loss and damage effects, and fluid velocity. However, with the differences between basic fluid properties, chemical properties, container material strength, temperature, etc., there is no reason to believe that these limits will apply to the liquid-metal pumps. Although considerable effort has been expended to date on liquid-metal flow tests in the range of pipe-line velocities, little has been done in the range of the necessarily much higher velocities to be encountered in pump impellers, and nothing has been done with respect to cavitation.

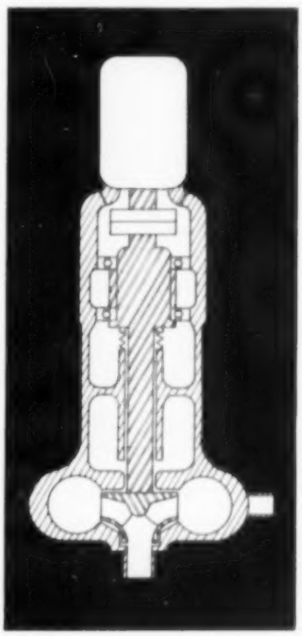


Fig. 11. Liquid-metal pump and drive, vertical overhung shaft, inert gas blanket, motor drive.

Problems

One of the present problems associated with the use of liquid metals is the relatively undeveloped state of the art of handling and pumping these fluids. With respect to pumps, this raises problems of sealing, bearing arrangement, mechanical construction with high-temperature gradients, and other problems related to physical construction. It also raises fluid dynamic problems with respect to cavitation, erosion, and pump flow-path design in general. The meager experience data presently available seem to indicate

* Although vapor pressures are low, the combination of flow and pump inlet pressure is such that fluid pressure less than the vapor pressure (and even negative) would be attained if pump speeds desirable from the mechanical-design viewpoint were used. There are at the present time several examples of liquid-metal cavitation.

† Mr. Hammitt is an associate research engineer in the Institute and lecturer in the Mechanical Engineering Department.

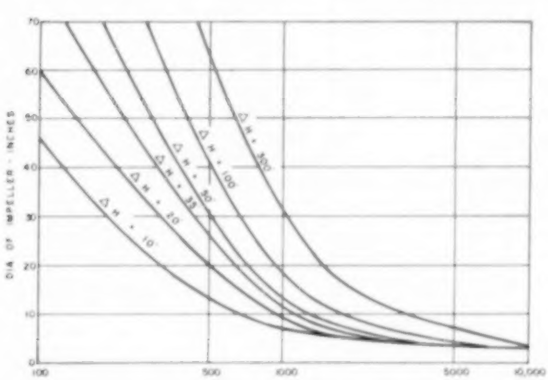


Fig. 1. Impeller diameter vs. pump speed for various head rises at 1,000 gal./min.

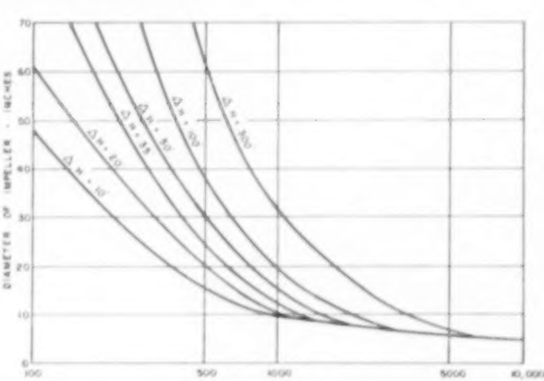


Fig. 2. Impeller diameter vs. pump speed for various head rises at 5,000 gal./min.

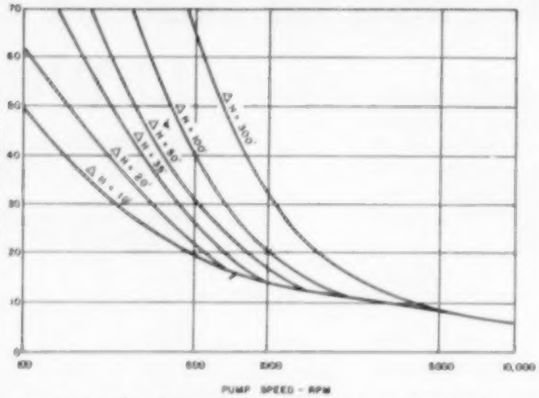


Fig. 3. Impeller diameter vs. pump speed for various head rises at 10,000 gal./min.

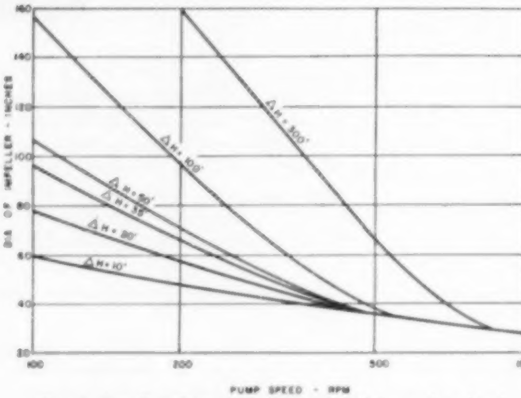


Fig. 4. Impeller diameter vs. pump speed for various head rises at 100,000 gal./min.

that the parameters of head, flow, and efficiency scale fairly well in the conventional way. However, to the author's knowledge, no information is available from long-term tests under the high velocity, high temperature, and perhaps cavitating conditions which would be encountered in a full-scale pump for a large nuclear power plant, for example. To complicate the matter further in this case, there is the question of radioactivity effects being added to the conventional erosion and cavitation effects. The cavitation phenomenon itself might be complicated in this respect by the introduction into the fluid of fission product gases, such as, perhaps, polonium. This situation represents a serious deficiency in the developmental programs presently underway.

Present Limitations on Liquid-Metal Pump Design

GENERAL PUMP TYPES

Of the various conventional pump types, in general only the centrifugal pump is of importance because of the large flow rates which are usually involved. However, since liquid metals are usually good electrical conductors, there is also the possibility of an electromagnetic pump. Compared to the centrifugal pump, the electromagnetic design offers the advantage of a completely welded system; however, with respect to weight, cost, and efficiency, it is inferior. Because of the excessive weight of the electromagnetic pump and its associated components, it is indeed prohibitive in design where weight is at a premium. With the variation between the various fluids to be pumped, sodium and potassium are far more suitable for an electromagnetic pump than are bismuth and its alloys because of the difference in conductivity.

PUMP REQUIREMENTS

For nuclear reactor applications liquid-metal flow rates in excess of at least 10,000 gal./min. will probably be required. Generally, it is not desired to increase pump suction pressure above a rather small value which depends on factors involving the over-all system.

Fig. 5. Cost-and-weight index vs. pump speed for various head rises at 1,000 gal./min. For liquid-metal pump and drive, vertical overhung shaft, inert gas blanket, motor drive.

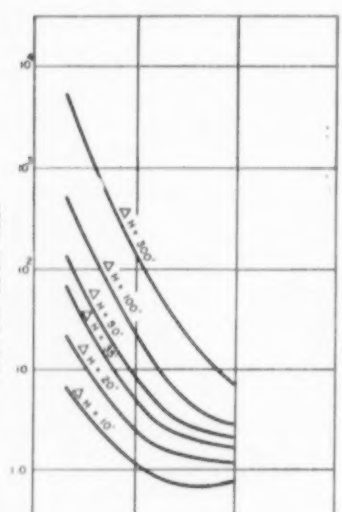


Fig. 6. Cost-and-weight index vs. pump speed for various head rises at 5,000 gal./min. For liquid-metal pump and drive, vertical overhung shaft, inert gas blanket, motor drive.

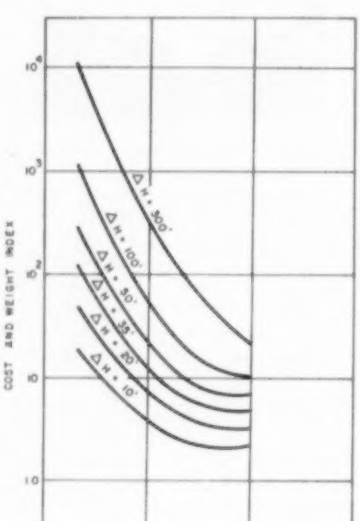
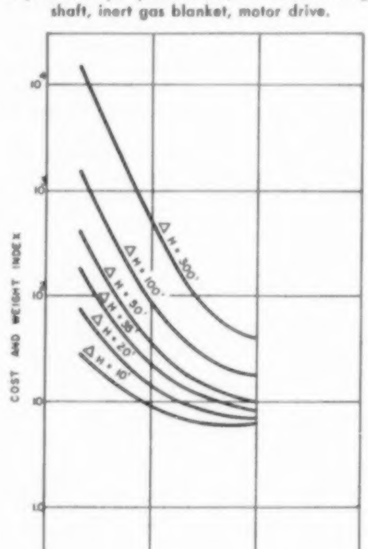


Fig. 7. Cost-and-weight index vs. pump speed for various head rises at 10,000 gal./min. For liquid-metal pump and drive, vertical overhung shaft, inert gas blanket, motor drive.



A typical specification, for example, would allow 10 ft. in excess of atmosphere (or about 50 ft.) for a 12,000 gal./min. sodium pump. (The net positive suction head would be somewhat less because of the vapor pressure of sodium.) A similar arrangement for bismuth would give a total suction pressure of only about 14 ft. because of the difference in densities.

Pump head rise requirements cover the full range from a few feet to several hundred feet. It is usually a compromise value between the high velocities desired for high heat transfer on one hand, and pump cost, complexity, and power requirements on the other. Because of the greater power required to pump a given volume flow rate of bismuth through a given head drop, the design head requirements for a bismuth-cooled system would tend to be smaller than for a sodium system. Heat capacity per unit volume is about the same for sodium and bismuth. The required head for the typical example previously cited (12,000 gal./min. sodium system) is about 400 ft. Presumably, if bismuth were the coolant, a lower figure would have been selected since otherwise the power requirements would be excessive.

CENTRIFUGAL PUMP DESIGN LIMITATIONS—CAVITATION AND HIGH FLUID VELOCITY EROSION

The weight and cost of a centrifugal pump and driver installation can be reduced most effectively by increasing the operating speed. In general, this effect is greatest in the low specific speed range where large reductions in pump diameter are attained through speed increase. Thus the importance of increasing pump speed depends on the relation between flow rate and required head rise. This is illustrated in Figures 1, 2, 3, and 4 * where the impeller diameter is plotted against pump speed for a range of required heads. Each curve is for a given flow rate—1,000, 5,000, 10,000 and 100,000 gal./min. were considered. In the 10,000 gal./min. case (Figure 3), for example, if the required head were 300 ft., increasing speed up to about 5,000 rev./min. would still result in a substantial reduction in diameter. However, if the required head were only 10 ft., most of the benefit of speed increase would be achieved at 1,000 rev./min. In the 1,000 gal./min. curve (Figure 1), a substantial diameter reduction with speed up to 10,000 rev./min. is shown. These curves are, of course, approximately applicable to single-stage † centrifugal and axial-flow pumps in general, and do not depend upon the particular fluid.

To illustrate the approximate variation of pump-driver weight with flow rate, head rise, and pump speed for a particular type of design for a particular fluid, the curves shown in Figures 5, 6, 7, and 8 are included. These illustrate only approximate trends and are not intended as accurate data. Each curve applies to a particular flow rate: 1,000, 5,000, 10,000 and 100,000 gal./min. were considered. The weight values are based approximately on a typical type of bismuth circulating-pump design with vertical long-overhang shaft, inert gas blanket, mechanical seal, and electric motor drive.‡

Since for similar types of machines in a somewhat restricted size range, cost and weight are more or less proportional, the vertical axis is called a cost-and-weight index. Although these curves are meant to apply only to a specific type of design, they show trends which are more or less applicable for any type of centrifugal

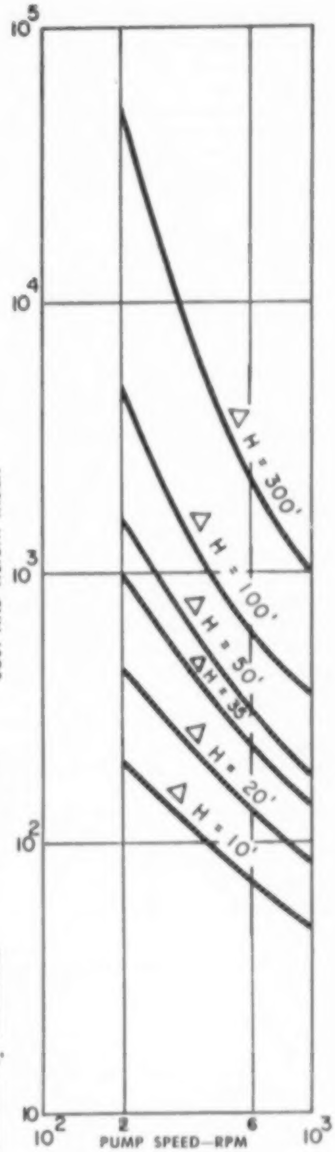
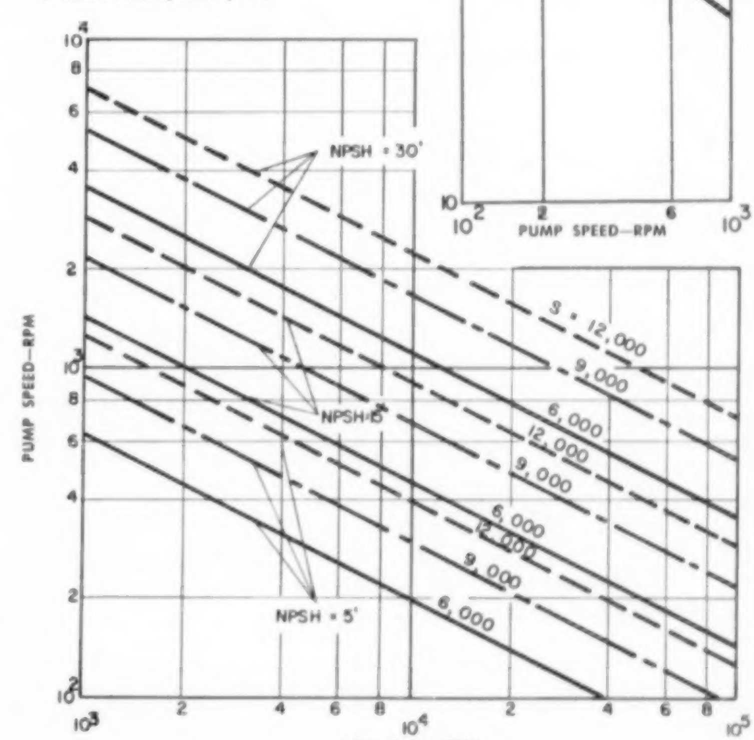


Fig. 8. Cost-and-weight index vs. pump speed for various head rises at 100,000 gal./min. For liquid-metal pump and drive, vertical overhung shaft, inert gas blanket, motor drive.

Fig. 9. Pump speed vs. flow rate for various suction specific speeds.



* The assumptions and sample calculations for these curves are shown in the Appendix.

† Only single-stage pumps are considered for the present because of the added mechanical complexities (overhung shaft, difficult bearing design, seals, etc.) of multistaging with high-temperature liquid metals.

‡ Detailed assumptions, sample calculations, and a sketch are given in the Appendix.

or axial-flow pump design. It will be noted that up to a certain point, that is, for low specific speed units, the pump cost and weight for a given flow and head rise are approximately proportional to the square of the speed, so that doubling the speed would achieve a fourfold saving.

In most actual liquid-metal circulating-pump designs for nuclear power plants, the pump speed is limited by the necessity of avoiding any possibility of cavitation. However, there is also the possibility of destructive erosion due to the high fluid velocity in the impeller. In general, for pumps in the range considered here, the relative velocity in the inlet section is greater than that at discharge. This value, as affected by the cavitation parameter S, is shown in Figure 10 (see Appendix D). However, there is still the necessity of achieving the discharge velocity to obtain the required head in a single-stage unit, and this value is only slightly affected by pump speed. Due to the lack of knowledge regarding the cavitation phenomenon in the various liquid metals with respect to both damage and performance, it is necessary at present to design with extreme conservatism. Thus, the cost, size, and weight of the proposed designs may be unnecessarily great; also the designs may be unduly complicated mechanically by the necessity for added shaft overhang.

A commonly employed measure of the likelihood of cavitation in a given design is the suction specific speed S, which is defined as

$$S = \frac{N\sqrt{\text{gal./min.}}}{(NPSH)^{3/4}}$$

where

N = rev./min.

$NPSH$ = net positive suction head-ft. of fluid

Wislicenus (*1*) showed that with the uncertainties of the actual flow conditions in a centrifugal rotor and the pressure coefficients which would probably be obtained with present-type blades, it is most probable that the vapor pressure is reached at some points within the impeller with S values above about 8,000. Thus, for conservative design in an unknown medium, an S of about 6,000 should be selected. However, there are many examples of pumps operating at S values of the order of 12,000 in water and other fluids with no discernible cavitation effects. Thus, even though water pumps can in many cases attain this latter value, and operate without damage even under fairly high velocity conditions, there is no basis for the assumption that the same value is feasible in an elevated-temperature liquid-metal system (or, on the other hand, for the assumption that it cannot be exceeded in some cases). Also, there is no assurance that the fluid velocities necessary to attain the desired heads in single-stage units will not result in prohibitive metal erosion.

For fluids other than water it is necessary to consider not only the effect of density (up to 10 for bismuth) and high temperature which weakens the structural materials, but also various chemical effects. On the other hand, in some cases, the tension-bearing capability of the fluid may be such as to prevent cavitation even if negative pressures are reached.

To show the effect of the S value on pump design, Figure 9 is included. For three typical N.P.S.H. values, and for three typical S values under each of these, the allowable pump speed is shown as a function of flow rate. It was assumed that an S of 6,000 represents present-day conservative design practice for liquid-metal pumps. It is believed that this statement would approximately represent the opinion of the major pump manufacturers. However, it is felt that an S of 12,000 or even

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APPENDIX A

IMPELLER DIAMETER VS. PUMP SPEED CALCULATION FOR VARIOUS HEADS (Figures 1, 2, 3, 4)

For radial- and mixed-flow units:

$$V = \frac{\pi DN}{60 \times 12} = \Phi\sqrt{2gH} \qquad \text{(A-1)}$$

where

- D = mean impeller discharge diameter (in.)
- N = rev./min.
- g = acceleration of gravity, ft./(sec.)(sec.)
- H = pump head rise (ft.)
- Φ = empirical constant based on specific speed

In general Φ varies from about 1.0 for low specific speed units to perhaps 1.2 for mixed flow units.

For cases where inlet eye diameter exceeded required impeller discharge diameter, the eye diameter was considered to be the controlling diameter.

The eye diameters were calculated by use of empirical ratios of N.P.S.H./$(Va^2/2g)$ for the various suction specific speeds desired.

APPENDIX B

PUMP WEIGHT AND COST ESTIMATE (Figures 5, 6, 7, 8)

A motor-driven, gas-sealed, vertical, high-temperature bismuth pump design was considered as a basis. This is shown schematically in Figure 11.

The total weight of this design was considered to be influenced by the following, for a radial- or mixed-flow unit:

1) pump proper (impeller and casing up to bearing housing)
2) shaft and bearing assembly and bearing housing
   a) radial load (shaft deflection)
   b) thrust load (bearings)
2') shaft and bearing assembly and bearing housing for axial-flow units
3) motor

For an axial unit, it was considered that shaft design was influenced primarily by critical speed, rather than radial impeller load. Otherwise the assumptions were the same as for the radial- and mixed-flow designs.

A typical unit of 35 ft. head rise, 5,000 gal./min., 700 rev./min., 18-in. impeller diameter was considered. It was assumed that portions 1), 2), and 3) would have relative weights of 7, 5, and 8, respectively. The other units were prorated from this basis. This assumption is based roughly on previous design studies.

1. *Pump Proper* (impeller and casing up to bearing housing)

It is assumed that the pump casing thickness depends on pressure stress. Then

$$W_1 \propto D_e^2 t b^{1/3} \qquad \text{(B-1)}$$

D_e^2 represents the radial area of the sides of the casing, t is wall thickness, b is casing axial length. Since weight is not directly proportional to width, a factor of $b^{1/3}$ was used.

Then $t \propto HD_e$ where H is head rise and D_e is casing diameter. It is assumed that the pumped fluid is bismuth and thus H is proportional to pressure.

$$b \propto \frac{\text{gal./min.}}{VD} \qquad \text{(B-2)}$$

V is peripheral impeller discharge velocity = DN. Thus

$$b \propto \frac{\text{gal./min.}}{D_e^2 N} \qquad \text{(B-3)}$$

Then

$$W_1 \propto \frac{D_e^2 HD(\text{gal./min.})^{1/3}}{D_e N^{1/3}} = K_1\frac{HD_e^2(\text{gal./min.})^{1/3}}{N^{1/3}} \qquad \text{(B-4)}$$

2. Shaft and bearing assembly, bearing housing for radial- and mixed-flow units

a. Shaft

It is assumed that shaft length is fixed by sealing and installation requirements, and that shaft diameter is determined by reflection under radial load.

Radial force:

$$F_R \propto HbD_1 \qquad \text{(B-5)}$$

$$\text{Shaft deflection} \propto \frac{F_R L}{I} \propto \frac{HbD_1 L}{D_{sh}^4} = \text{constant} \qquad \text{(B-6)}$$

where L is shaft length and is a constant for this purpose, and allowable deflection is a constant of the design. D_{sh} is shaft diameter.

Then

more might become feasible in certain liquid-metal pump applications if further basic knowledge on cavitation in liquid metal were available. This value then was used for the upper limit on the curves.

It will be noted that if the previously mentioned example of a 12,000 gal./min., 400-ft. head, 50-ft. suppression head is considered, the speed based on the conservative S value is about 1,030 rev./min., and the cost-and-weight index about 1,600.* For S of 12,000, the speed is 2,060 rev./min. and the cost-and-weight index is about 400; the result is a fourfold saving. As another example: a 10,000 gal./min. bismuth pump might be considered with a head rise of 20 ft. and a net positive suppression head of 15 ft. (about 10 ft. over one atmosphere). This is approximately typical for one kind of application. Then for S of 6,000, the pump speed is about 450 rev./min. and the cost-and-weight index is 26; for S of 12,000 the speed is 900 rev./min. and the cost-and-weight index is 15. Here the saving is not so great as in the first case although it is still substantial.

Also one can note that for lower flow rates, if the heads are as given, the proportional saving becomes greater, approaching the ratio given for the case of the sodium pump. The cost-and-weight indices for the two cases should not be compared directly since the tenfold density difference between sodium and bismuth would increase considerably the cost and weight of the bismuth pump with respect to the sodium pump. Also there may be differences in temperatures, applicable materials, and sealing arrangements.

It thus appears that from the viewpoint of economics there is considerable justification for a liquid-metal cavitation study program since the cost of a single pump-driver unit may be several hundred thousand dollars. From the viewpoint of those applications where weight saving is important, as for example in aircraft or other forms of transportation devices, such a program would seem to be absolutely vital. Also, it may be necessary to conduct high velocity tests, even when cavitation is absent, to demonstrate the feasibility of single-stage centrifugal pumps producing the desired heads since relative fluid velocities in the impeller are of the order of five to ten times the conventional pipe-line velocities (Figure 10).

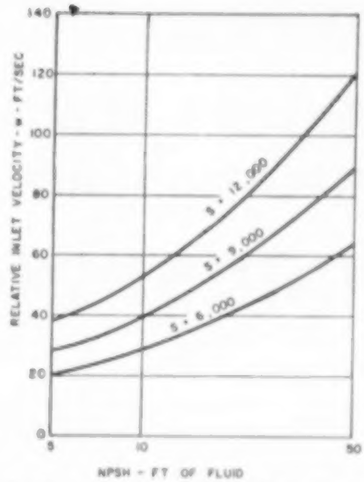

Fig. 10. Impeller relative inlet velocity vs. net positive suction head for various suction specific speeds.

Literature Cited

1. Wislicenus, G. F., *Trans. Am. Soc. Mech. Engrs.*, **78**, 1707-14 (November, 1956).

* Impeller diameter is about 37 in. The entire pump-casing diameter would be about 6 ft.

$$D_{sh} \propto (HbD_i)^{1/4} \qquad \text{(B-7)}$$

and

$$W_{2a} \propto (HbD_i)^{1/2} = K_{2a}\left(\frac{H\text{gal./min.}}{D_iN}\right)^{1/2} \qquad \text{(B-8)}$$

since $bD_e \propto \dfrac{\text{gal./min.}}{D_eN}$ by (B-3) and $D_i \propto D_e$. D_i = impeller diameter

b. Bearing Assembly and Housing

Assume the total weight for these components is proportional to bearing weight which is assumed primarily affected by required thrust capacity.

Bearing thrust capacity (assuming anti-friction bearings) is approximately proportional to $D_b^2/N^{1/4}$. (Values were tabulated from New Departure Catalog.) Bearing weight must be approximately proportional to $D_b^2b_b$, where D_b is bearing width and b_b bearing axial dimension. Also D_b and b_b are proportional to each other. Then thrust capacity,

$$F_T \propto \frac{\text{weight of bearing}}{D_bN^{1/4}} \qquad \text{(B-9)}$$

On the other hand, pump thrust is proportional to HD_i^2. Equate thrust and thrust capacity. Assuming that $D_b \propto D_{sh}$; substitute $D_{sh} \propto (HbD_i)^{1/4}$ (B-7), and

$$b \propto \frac{\text{gal./min.}}{D_e^2N} \text{ by (B-3)} = \frac{\text{gal./min.}}{D_i^2N}$$

$$W_{2b} = K_{2b}H^{5/4}D_i^{7/4}\,\text{gal./min.}^{1/4} \qquad \text{(B-10)}$$

2'. Shaft and Bearing Assembly and Bearing Housing for Axial Flow Units

a. Shaft

It is now assumed that shaft diameter is controlled by critical speed considerations since the radial load is not high for an axial flow pump.

f is approximately proportional to $(\delta)^{-1/2}$ where δ = deflection under impeller weight and f = natural frequency.

$f \propto N$ (since a safe proportion over the operating speed must be maintained).

$$\delta \propto \frac{\text{Wgt}_i}{D_{sh}^4} \propto \frac{1}{N^2} \text{ or } D_{sh} \propto (\text{Wgt}_iN^2)^{1/4} \qquad \text{(B-11)}$$

Assume impeller weight for an axial impeller,

$$W_i \propto bD_i^2 \qquad \text{(B-12)}$$

and that $b \propto D_i$. Then

$$\text{Wgt}_i \propto D_i^3 \qquad \text{(B-13)}$$

$$W'_{2a} \propto D_{sh}^2 = K_{2a}'D_i^{1.5}N \qquad \text{(B-14)}$$

by substituting (B-13) into (B-11).

3. Motor

Data were gathered for existing motors from Kent's Mechanical Engineers' Handbook and from the General Electric Company.

$BHP \propto$ gal./min. $\times H$ for the pump.

It was noted that approximately

$$W_3 \propto \frac{BHP^{0.8}}{N^{1/2}} = K_3\frac{(\text{gal./min.})^{0.8} \times H^{0.8}}{N^{1/2}} \qquad \text{(B-15)}$$

The curves shown in Figures 5, 6, 7, and 8 are approximate plots of the results from these calculations. It will be noted that for a given head and flow, pump weight is reduced more drastically for low specific speed units than for high. This result is reasonable since for the high specific speed and axial units, diameter reduction is not accomplished by increasing speed. In fact extreme speed increases show a weight increase because the shaft weight increases (because of fixed length and critical speed requirement) faster than the motor weight decreases.

These curves are included only to show the approximate trends and are not intended as accurate data.

APPENDIX C

PUMP SPEED VS. FLOW RATE FOR VARIOUS SUCTION SPECIFIC SPEEDS (Figure 9)

This is simply a plot of the relation

$$S = \frac{N\sqrt{\text{gal./min.}}}{(NPSH)^{3/4}} \qquad \text{(C-1)}$$

APPENDIX D

RELATIVE INLET VELOCITY VS. NPSH (Figure 10)

For a given suction specific speed there are empirical constants relating the maximum desirable fluid velocities to the N.P.S.H. From one version of these relations the relative fluid velocity at impeller inlet at the outside periphery of the impeller was calculated for various N.P.S.H. with suction specific speed as parameter. These are plotted in Figure 10. This is not intended as exact data and does not imply that for a given S and N.P.S.H. only one relative velocity is possible. However, it shows the order of magnitude and trend of the variation to be expected in present-day design practice.

ENERGY-NEW SURFACE RELATIONSHIP IN THE CRUSHING OF SOLIDS

In this investigation of the effect of temperature on the relationship between energy input and external surface produced in the impact crushing of certain brittle solids, a drop-weight type of crusher was used so that results could be easily correlated with those obtained by previous workers. The new surface produced was measured by the air permeability method. Operating temperatures were limited by the available facilities and materials of construction to the range of −58° C. to 400° C. The test materials included three grades of taconite, pure quartz, a high purity magnetite, a fine-grained specular hematite, and glass.

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Many of the known economic mineral deposits of the United States are being rapidly depleted in supplying an ever-expanding economy with the necessary materials of construction, maintenance, and war. Consequently, the development of marginal and submarginal mineral deposits has become a matter of necessity as well as one of economics. Utilization of low-grade ores almost invariably requires extensive size reduction which accounts for an appreciable proportion of the total milling costs in the mineral industries (*7*). In the beneficiation of taconite, the low-grade magnetic iron ore found on the Mesabi Range in Minnesota, the cost of comminution to minus 200-mesh represents 5 to 15% of the final ore costs at the mine (*4-6, 12*).

This work constitutes an extension of the crushing research program of this laboratory (*1-3, 9, 11*). It was considered that measurement of the effect of temperature on the crushing process is of basic interest to the development of a comprehensive theory of crushing and needed to be demonstrated quantitatively. With this object in mind, several solids of varying characteristics were investigated. The immediately practical objective was to determine whether or not the cost of size reduction of taconite could be reduced through proper temperature control during the crushing operation.

Test Materials

Materials selected for investigation included pure quartz and a high-purity magnetite (which are the chief constituents of taconite), three grades of taconite, a fine-grained specular hematite, and glass, as listed in Table 1.

Preparation of the pure minerals consisted in crushing, recovering the 4/8-mesh size fraction, washing with acetone to remove the adhering fines, and drying. The glass, furnished as single strength sheets 0.25 cm. thick was cut into squares averaging 0.9 cm. on a side. The quartz and the glass used were portions of the same lots previously reported on by this laboratory (*1*). The taconite samples, 4/8-mesh, were prepared by crushing and screening a suitable quantity of ½-in., banded taconite, washing, and drying. The sized material was then separated into three grades by multiple passes over a small magnetic drum separator. (See Table 2.) Each fraction was then rewashed in acetone and dried.

Crushing Equipment

Crushing tests were performed in a drop-weight crushing device such as previously described (*11*). The method consisted of dropping a steel ball of known weight from a measured height to drive a steel piston against the sample contained in a cylindrical, steel crushing chamber.

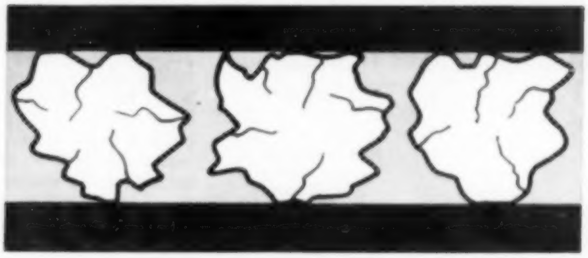
Minor modifications were incorporated in the crushing equipment and procedure to facilitate tests at elevated and at subzero temperatures. The mortar assembly used here was constructed of hardened and tempered high-speed tool steel (18.25% W, 3.75% Cr, 1.15% V). The mortar was 3.24 in. high, 3.94 in. diam., with a cavity 2.52 in. deep by 2.50 in. diam. The plunger was 2.45 in. long by 2.50 in. diam., machined to fit in the mortar cavity with radial clearance of less than 0.001 in. The ball was the same 3.3 in. diam., 2.52 kg., carburized steel ball previously used. A thermocouple well was drilled at an angle from the top edge of the plunger to a point on its axis ¼ in. from the center of its contact face.

For the prevention of rebound of the ball, it was found to be unnecessary, as well as impractical at the extreme temperatures involved, to place cushion wires between the mortar and its supporting base. Ball rebound was avoided by stirring the crushed material in the mortar cavity between blows.

Accessory equipment included a cylindrical electrical resistance furnace for use in tests at elevated temperatures up to 400° C., and refrigeration equipment for use in tests at subzero temperatures down to −58° C.

Measurement of Energy in Crushing Operation

The net energy consumed by the crushed material during the crushing operation was calculated by an "efficiency" method that differed from the "difference" method introduced by Gross and Zimmerley (*8*) and used by other research workers in this laboratory (*1, 3, 9, 11*). In the difference method, the net energy input was taken to be the summation of the products of the weight of the steel ball by its height of drop for each blow diminished by that height of drop which would have given the same average cushion wire deformation if the mortar cavity had been empty. In this investigation no cushion wires were used, and an efficiency method of calculation was used in which the net energy input to the material was taken as the sum of the products of the weight and



height of drop of the steel ball, and the summation was then corrected for elastic deformation losses in the ball and mortar assembly by means of a correction factor. This correction factor was in the form of a mortar efficiency, obtained through the use of aluminum cushion wires which were deformed in the mortar cavity in mortar calibration tests.

The mortar calibration tests were performed with accurately cut pieces of No. 12 B & S gauge mildly annealed aluminum wire 1 cm. long. Three such wires were placed at a time with their axes parallel to the anvils of an Amsler Hydraulic Test Machine and compressed slowly to a measured final load. The resulting thicknesses of the deformed wires were measured with a micrometer. The energy of deformation was then calculated as a function of final wire thickness. This function was assumed to be independent of the rate of deformation of aluminum in the range from that occurring in the slow compression testing machine to that occurring in the drop-weight crusher (*10*). Further data were then obtained by substituting calibration wires for the brittle materials in the cavity of the drop-weight crusher and measuring the wire deformation resulting from dropping the ball on the plunger. The difference between the kinetic energy applied to the crusher and the energy of deformation of the wires, as determined from the energy-thickness function obtained by slow compression, was assumed to be due to elastic deformation losses in the ball and mortar assembly.

Similar mortar calibrations were obtained at elevated and at subzero temperatures through the use of thermally insulated face-plates in the mortar cavity. The additional energy losses in the face-plates were determined for the standard 40-cm. height of drop of the ball by difference between wire deformation energies obtained with and without the face-plates at room temperature. These face-plate energy losses were assumed to vary negligibly with mortar temperature within the range employed.

Results of the mortar calibration tests showed that the mortar assembly delivered a constant proportion, about 77%, of the gross energy input to the aluminum wires in the mortar, regardless of temperature, number of wires present, height of drop of the steel ball between 10 and 60 cm., or number of blows up to an accumulated energy input of about 50 kg.-cm./wire. Other calibration wires of steel and copper, which tended to work-harden, absorbed more or less of the gross energy, respectively, than did the aluminum. The elasticity loss in the mortar assembly when crushing brittle materials was assumed to be identical with that occurring when the aluminum calibration wires were deformed, that is, 77% of the gross energy input was delivered to the material being crushed. It is believed that errors arising from such an estimation of energy loss to the crusher had no effect on the relative results obtained when crushing a given material, but may have introduced uncertainties amounting to perhaps 10% when comparing results obtained on two different minerals.

The efficiency method of net energy input calculation used here gave better correlations of data obtained in two similar crushing assemblies in which different types of steel were used (Figures 1 and 2). Mortar K-3, made of hardened high-speed tool steel as described in a foregoing section, was used in all but a few tests at 25° C. on glass. Runs G-1, 2, 3, 4, and 5 were made in Mortar K-2, constructed of hardened carbon steel (*9, 11*). A comparison of the 25° C. crushing data on glass, Figures 1 and 2, shows that, whereas the points obtained in Mortar K-2 do not lie on the same curve as those obtained in Mortar K-3 when calculated by the difference method, the plots of the two sets of data are indistinguishable when calculated by the efficiency method. The slopes of the area-energy plots are greater when the data are calculated by the efficiency method than when calculated by the difference method, as shown by comparing Figures 1 and 2 (Table 3) for glass and also curves *D* (*9*) and *E* in Figure 3 for quartz. When cushion wires are used, the data in Table 3 indicate that the net energy input for glass calculated by the difference method is 15% too high. This percentage varies with the fraction of the total energy input absorbed by the cushion wires. For experiments in which cushion wires were not used, a correction

Fig. 1. Energy-new surface relationship for glass; energy by difference method, areas by air permeability.

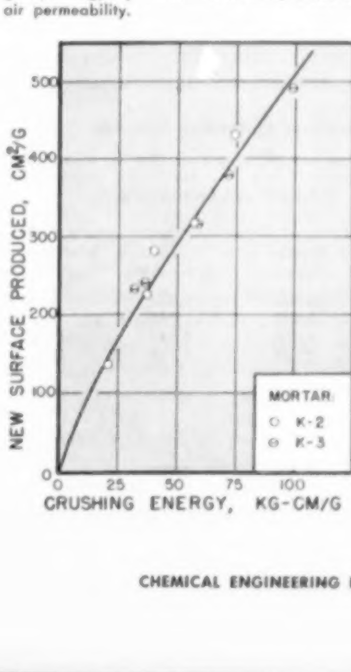
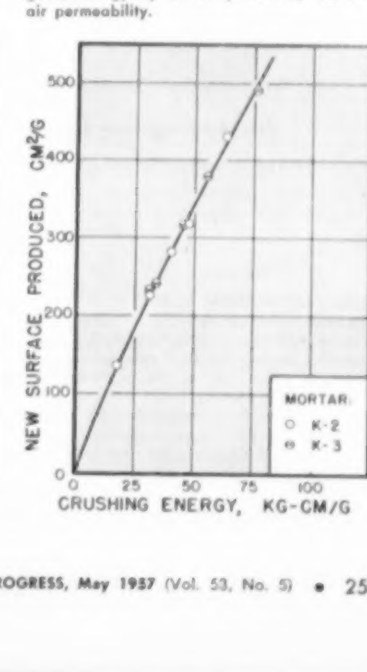


Fig. 2. Energy-new surface relationship for glass; energy by efficiency method, areas by air permeability.



for mortar losses could not be applied by the difference method and the net energy input was necessarily equal to the gross energy input.

There was no certain method for determining how much of the gross energy input was consumed in producing the score marks on the contact faces of the plunger and mortar. Microscopic examination of these score marks led to the belief that the energy consumed in their formation could be as high as 20 to 50% of the gross energy input when crushing quartz. No correction was made for this loss because of lack of reliable information on the subject. Further work needs to be done here. The amount of scoring produced at −58° C. was observed to be considerably less than at −32° C. and may easily have accounted for the increased crushing efficiencies found for all materials tested as the temperature was decreased from −32 to −58° C.

Table 1.—Materials Tested

Material: origin and description	Moh hardness	Density, g./cc.	Approximate composition
MAGNETITE: Ural Mtns.[a]; massive, not magnetic in itself, occasional occluded quartz grains.	5.5–6.5	5.02	97% magnetite
TACONITE: Mesabi Range[b]; heterogeneous, grain size from microscopic to 1 mm. or more.	—	3.45	50% magnetite, balance mainly quartz and silicates
QUARTZ: Hot Springs, Ark.[c]; clear, large crystals.	7.0	2.65	100% quartz
HEMATITE: Brazil; fine-grained, massive, specular, slightly porous.	5.5–6.5	5.03	99.8% hematite
GLASS: Ford Motor Co., St. Paul, Minn.; single-strength glass for automobile windows.	5.0–6.0	2.50	SiO_2 71.73%; CaO 9.77; Fe & Al oxides 1.20; MgO 4.00; Na_2O 13.30

[a] From U. S. Bureau of Mines Experiment Station, University of Minnesota.
[b] Ore No. 959, Minnesota Mines Experiment Station. Origin: Eastern Mesabi, Upper Mitchell Horizon, near Babbitt, Minnesota.
[c] From Wards Natural Science Establishment, Inc., Rochester, New York.

Table 2.—Magnetic Separation of 4/8-mesh Taconite.

Fraction	Recovered weight, g.	Per cent of total	Avg. density g./cc.	Magnetite content per cent
Concentrate	598	24.0	4.24	77
Middlings	1,018	41.5	3.52	51
Tailings	849	34.5	2.98	23
Composite	2,465	100.0	3.45	50

Table 3.—Comparison of Crushing Energies of Glass at 25° C. as Calculated by Two Methods

Test No.	New surface produced sq. cm./g.	Gross energy input, kg.-cm./g.	Net energy input, kg.-cm./g. Difference method	Net energy input, kg.-cm./g. Efficiency method
G-1	136	33.4	20.9	17.5
G-2	226	65.5	36.8	31.6
G-3	318	99.4	56.8	48.2
G-4	431	132.9	74.2	63.7
G-5	282	91.3	46.7	40.2
SG-1*	379	71.7	—	55.3
SG-2	241	55.6	36.1	34.0
SG-3	233	55.6	31.8	31.2
SG-16*	317	58.7	—	45.1
SG-17*	492	99.5	—	76.2

* No cushion wires used.

Table 4.—Comparison of Specific Surfaces of Crushed Minerals

Determined by Air Permeability and by Krypton Adsorption (Parking Area 19.5 sq. Å/molecule).

Material	Specific surface, sq.cm./g. Krypton adsorption	Specific surface, sq.cm./g. Air permeability	Ratio of areas, adsorption to permeability
Glass, −200 m., SG-17	3,540	2,074	1.7
Magnetite, −200 m., SM-22	2,500	986	2.5
Taconite Middlings, −200 m., STM-12	3,670	1,540	2.4
Hematite, special sample, of material tested	3,740	1,102	3.4
Hematite-goethite ore, 62.4% Fe, Mesabi Range. (Not used in crushing tests.)	128,600	2,060	62.4
Quartz, as used in crushing tests, by ethane adsorption (9).	—	—	2.0
Quartz, crushed Ottawa sand (Not used in crushing tests.)	5,890	2,800	2.1

Experimental Methods

The crushing operations for this investigation were standardized to eliminate as many extraneous variables as possible. The quantity of material crushed was kept constant for all tests at 8 cc. vol. of solid material. The initial sample particles were randomly arranged in the cavity in such a way that only a few were in contact with the piston. This was especially necessary in the case of the glass platelets to ensure that the energy applied in a single blow would shatter the particles. Otherwise elastic deformation of the material would have caused appreciable rebound of the ball.

All samples were crushed in the air-dried condition without benefit of a moistening agent. The crushing energy was applied by dropping the steel ball the required number of times from 40-cm. height to accumulate the desired gross energy input of 35, 60, or 100 kg.-cm./g. of material. At lower energy input too little crushing was accomplished for convenient area measurements, and at higher energy input the dusting loss of fine material became excessive. In every case, all the material was allowed to remain in the mortar until completion of the crushing operation. Occasional stirring of the crushed materials in the mortar was necessary to prevent compaction and consequent rebound of the steel ball upon striking the plunger.

Temperature control for elevated temperatures was obtained through the use of an electrical resistance furnace placed around the mortar. Subzero temperatures were obtained by placing the entire apparatus, exclusive of the steel ball, in a refrigerated room at −32° C. Still lower temperatures were attained by using an acetone-carbon dioxide bath and pumping refrigerated acetone through a cooling coil

placed about the mortar. Temperature measurements were made with a calibrated copper-constantan thermocouple with its junction in the well drilled into the plunger. Preliminary experiments indicated that the temperature so measured was within 5° C. of the temperature of the material being crushed, even at the extremes of temperature employed.

Extent of Crushing Accomplished

The production of new surface area was presumed to be the only useful result accomplished in the crushing operation. Crushed samples were carefully dry-screened into five fractions: plus 8, 8/14, 14/65, 65/200, and minus 200-mesh. The surface areas of the three finest fractions were determined by the air permeability method *(11)*. The small surface areas of the coarse fractions and of the initial material were satisfactorily estimated by applying the same relation between measured surface area and screen size as found in the finer sizes. As before, material lost during crushing and handling was assumed to have the same specific surface as the minus 200-mesh fraction and corrections were made on this basis *(11)*.

Specific surfaces of the minus 200-mesh fractions of selected crushed products were also measured by the krypton gas-adsorption method for comparison with air permeability areas, see Table 4. The differences in surface areas obtained by the two methods are to be expected *(11)* and are due in part to the fact that the air permeability method does not measure surface areas in small, deep crevices, cracks and pores, *culs de sac*. The correct value of the new surface area produced by crushing is probably greater than the air permeability value, and close to the gas adsorption value for nonporous materials. In the case of a porous mineral, the gas adsorption

Table 5.—Energy-Surface Area Data

Test No.	Temp. °C.	Net energy input, kg.-cm./g.	New surface produced, sq.cm./g.	Over-all crushing resistance, kg.-cm./sq.cm.
Glass:				
SG-27	−57	26.9	177	0.152
SG-28	−58	46.4	302	0.153
SG-29	−59	77.2	475	0.163
SG-24	−33	26.7	191	0.140
SG-25	−34	46.3	301	0.154
SG-26	−32	77.0	452	0.170
SG-3	25	31.3	233	0.134
SG-2	25	34.0	241	0.141
SG-16	23	45.1	317	0.142
SG-1	25	54.1	379	0.143
SG-17	25	76.2	492	0.155
SG-18	100	28.2	221	0.128
SG-19	101	43.8	330	0.139
SG-20	100	76.8	496	0.155
SG-10	172	25.1	170	0.148
SG-9	172	46.9	312	0.150
SG-21	171	54.1	326	0.166
SG-8	170	77.8	454	0.171
SG-7	290	26.7	161	0.166
SG-4	293	46.5	232	0.200
SG-22	292	53.9	340	0.158
SG-6	293	77.2	420	0.184
SG-13	400	24.2	160	0.151
SG-12	398	38.9	239	0.163
SG-15	403	45.5	280	0.163
SG-23	399	54.0	331	0.163
SG-11	400	71.5	443	0.161
SG-14	402	77.1	394	0.196
Quartz:				
SQ-21	−58	27.1	199	0.136
SQ-22	−58	46.2	280	0.165
SQ-23	−57	77.5	490	0.158
SQ-18	−32	27.2	178	0.153
SQ-19	−31	54.3	319	0.170
SQ-20	−33	77.3	436	0.177
SQ-12	24	27.1	220	0.123
SQ-13	25	46.5	362	0.128
SQ-14	25	77.3	551	0.140
SQ-17	99	27.2	194	0.140
SQ-16	99	46.4	329	0.141
SQ-15	101	77.4	531	0.145
SQ-4	201	27.1	228	0.119
SQ-5	201	46.3	358	0.129
SQ-6	201	76.7	543	0.141
SQ-7	299	27.1	215	0.126
SQ-9	299	46.4	365	0.127
SQ-8	301	77.2	538	0.143
SQ-3	397	25.0	186	0.134
SQ-11	402	46.6	369	0.126
SQ-1	400	43.1	321	0.134
SQ-10	400	77.3	570	0.136
SQ-2	397	71.6	505	0.142
Taconite Tailings:				
STT-15	−58	29.0	161	0.180
STT-14	−57	48.3	278	0.174
STT-11	−31	29.1	152	0.191
STT-12	−32	48.3	222	0.217
STT-7	26	28.9	171	0.169
STT-8	25	48.4	275	0.176
STT-9	101	29.1	169	0.172
STT-10	100	48.5	273	0.178
STT-2	197	29.0	177	0.164
STT-1	201	48.4	292	0.166
STT-4	301	29.1	175	0.166
STT-3	300	48.3	278	0.174
STT-6	400	29.1	190	0.153
STT-5	400	48.4	283	0.171
Taconite Middlings:				
STM-21	−56	27.6	123	0.224
STM-22	−55	47.0	200	0.235
STM-23	−58	77.3	288	0.268
STM-18	−32	27.6	115	0.240
STM-19	−31	47.0	177	0.266
STM-20	−32	77.6	256	0.303
STM-10	25	27.5	142	0.194
STM-11	26	46.9	219	0.214
STM-12	27	77.4	333	0.232
STM-13	100	27.6	131	0.211
STM-14	103	47.0	193	0.244
STM-15	99	77.5	320	0.242
STM-3	200	27.6	122	0.226
STM-16	200	47.2	193	0.244
STM-2	201	47.8	207	0.231
STM-1	200	76.6	295	0.260
STM-6	300	27.6	121	0.228
STM-5	302	47.0	209	0.225
STM-4	300	77.4	295	0.262
STM-9	400	27.6	130	0.212
STM-8	401	47.1	209	0.225
STM-7	401	77.6	339	0.229
STM-17	399	77.7	328	0.237
Taconite Concentrate:				
STC-7	−58	45.6	161	0.283
STC-6	−32	45.6	135	0.338
STC-4	26	45.6	192	0.238
STC-5	100	45.6	172	0.265
STC-1	204	45.5	173	0.263
STC-2	301	45.6	184	0.248
STC-3	401	45.6	187	0.244
Magnetite:				
SM-21	−38	27.0	101	0.267
SM-22	−56	46.8	146	0.318
SM-23	−57	77.3	249	0.310
SM-18	−31	27.1	92	0.295
SM-19	−33	46.3	143	0.324
SM-20	−33	77.4	232	0.333
SM-12	25	27.1	116	0.234
SM-13	26	46.5	191	0.243
SM-14	24	77.5	270	0.287
SM-15	101	27.1	118	0.230
SM-16	99	46.3	172	0.269
SM-17	100	77.4	274	0.282
SM-5	202	27.1	110	0.246
SM-6	201	46.4	160	0.290
SM-4	203	77.0	257	0.300
SM-9	300	27.0	112	0.241
SM-8	301	46.4	170	0.273
SM-7	301	77.1	244	0.316
SM-3	398	24.9	102	0.244
SM-2	398	42.8	150	0.285
SM-10	401	46.3	182	0.254
SM-1	401	71.5	231	0.310
SM-11	401	77.0	282	0.273
Hematite:				
SH-7	−57	49.1	151	0.325
SH-6	−33	49.1	140	0.351
SH-4	25	49.2	182	0.270
SH-5	100	49.2	184	0.267
SH-2	203	49.0	153	0.320
SH-3	301	49.0	174	0.282
SH-1	399	45.0	196	0.288

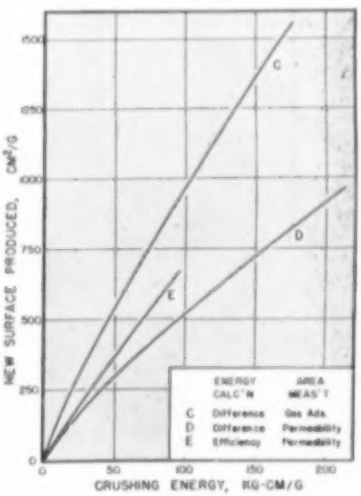


Fig. 3. Energy-new surface relationships for quartz by various methods [Data for C and D from (9)].

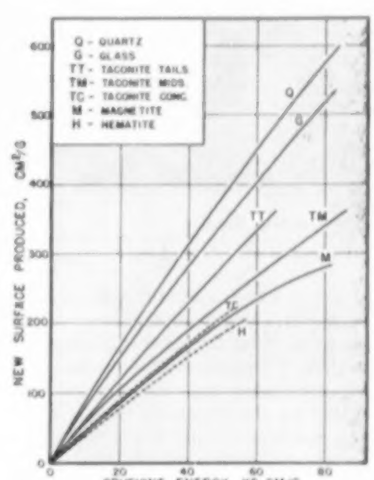


Fig. 4. Energy-new surface relationships at 25° C. Areas by air permeability, energy by efficiency method.

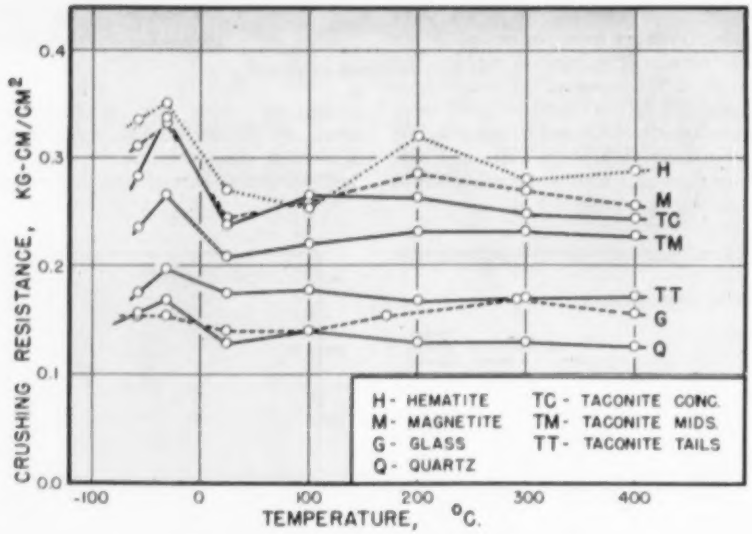


Fig. 5. Variation of crushing resistances with temperature.

method measures both the new surface area produced by crushing and also pre-existing internal surfaces made accessible by the fracture. A striking example of such a material was the hematite-goethite ore, listed in Table 4 for illustrative purposes, but not used in the crushing tests. For this material the gas-adsorption area of a pulverized sample was 62.4 times as great as the air permeability value. In this case the gas-adsorption method of area measurement gives a satisfactory value for use in adsorption or flotation work, but not for use as a measure of the extent of crushing.

Experimental Results

DISCUSSION

The original data obtained are presented in Table 5, of which those obtained at 25° C. are plotted in Figure 4 to show the relation between new surface produced and the energy consumed for the materials tested. Previous publications (*1, 9, 11*) have presented similar relationships for a variety of materials, intial sizes, and energy inputs. The effect of energy concentrations has been discussed (*2*), showing that this is an important factor. Further work on this aspect is in progress.

The crushing resistances plotted vs. temperature in Figure 5 have been calculated from the slopes of the area—energy curves at a net energy input of 46 kg.-cm./g.

The variation of crushing resistance with temperature was very small at temperature between 25 and 400° C. (See Figure 5.) In all cases where a

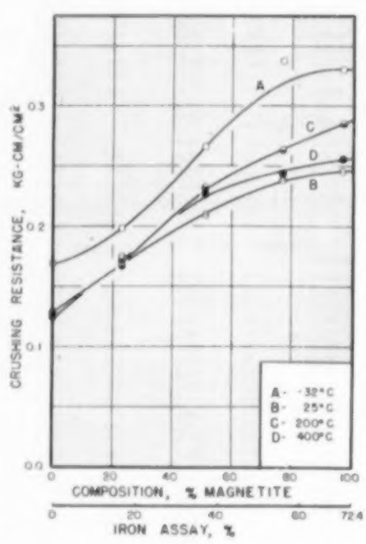


Fig. 6. Variation of crushing resistance of taconite with composition.

minimum crushing resistance could be discerned at all, such minima occurred at or slightly above room temperature. At −32° C., crushing resistances of all materials tested rose sharply, but dropped again at −58° C. It is suspected that the sudden drop in crushing resistances below −32° C. was due not so much to the properties of the materials being crushed as to variations in the energy lost to scoring of the contact faces because of changes in the properties of the steel used. Traces of water in the solids may also have been a contributing factor.

The crushing resistance of taconite was found to increase with the iron assay (Figure 6). A combination of the lower crushing resistance of quartz with the natural grain size of the taconite caused the 65/200-mesh fraction to contain a minimum proportion of magnetite. The quartz occlusions in the high purity magnetite were found to be concentrated appreciably in the minus 200-mesh fraction of the crushed product.

Finally, variations in temperature of crushing had no visible effect, microscopically or otherwise, on the shapes of the particles in the products nor on the nature of the fracture surfaces.

It may be added here that a 18-g. sample of glass particles was crushed about two months after having been radiated for some 10 days to a total dose of 79.5×10^6 roentgens of gamma radiation from a cobalt-60 source. No marked change in the area produced per unit work input was found between this sample and the untreated samples of the same glass.

Acknowledgments

The authors wish to acknowledge the assistance of the staff of the Mines Experiment Station, University of Minnesota, in procuring and preparing suitable samples of the taconite used. This investigation was supported in part by the Graduate School of the University of Minnesota and by a National Science Foundation Grant, NSF-G449.

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GIANT BUTADIENE PLANT GOES ON-STREAM

First new butadiene plant to be completed by private industry since World War II, the new Texas Butadiene & Chemical Corp. plant is dual purpose, incorporates major engineering innovations designed into it by Fluor Corp.

Located at Channelview, Texas, the new butadiene plant has just come on stream with the first of its two 43,000 ton-a-year Houdry Dehydrogenation Process units. The second unit is scheduled to be placed in operation shortly. Cost of the dual purpose plant is $30 million.

The plant will produce butylenes as feed for making aviation gasoline as well as butadiene. When both units are on stream, the plant will produce 61,000 tons of butadiene annually and about 2.5 million barrels of aviation grade alkylate. Alternatively, if the alkylate is not in demand or if butadiene demand increases, the plant can produce 86,000 tons of butadiene a year.

The first new butadiene plant to be built since World War II by private industry, it is only the third such plant to use the Houdry Dehydrogenation Process developed as part of the Government's wartime synthetic rubber program, and of the two previous units one is now dismantled and the other is still in operation at Standard of California's El Segundo refinery.

Each of the two Houdry Dehydrogenation Process units has seven horizontal reactors, and for the first time in a cyclically controlled plant the valves (bottom) are operated hydraulically.

Engineering Innovations

The Fluor Corp., which designed, engineered and constructed the new plant, has incorporated major innovations into the design and engineering. For the first time in a plant of this type, axial flow compressors have been used for hydrocarbon compression. (The new plant has nine gas and air compressors ranging in size from 2,500 h.p. to 10,000 h.p.)

Also for the first time in a major process plant, a central hydraulic power system actuates the cyclically operated reactor valves. This change was made since Fluor believes that it permits quicker operation and more positive movement than other methods.

Process Features

Developed by Houdry Process Corp., the process is a single step method employing an alumina-chrome oxide catalyst which transforms fresh butane into butadiene or butanes. (The fresh butane is usually mixed with butane-butene recycle stock from the Butadiene Recovery Section which employs the Phillips Furfural Extractive Distillation Process licensed by Phillips Petroleum.)

The mixed feed is heated before entering the catalyst chamber. The dehydrogenated effluent gases are compressed, passed through an absorber-stripper unit and fed to the Butadiene Recovery section.

Fluor also engineered and constructed all the off-site installations including all transportation and loading facilities.

K. D. Bowen, vice president and general manager of Texas Butadiene said that, "Initial operations have been satisfactory and indications are that the plant will operate successfully at design yield and production levels."

First butadiene recovery unit built since World War II uses a furfural extractive distillation process at Texas Butadiene's new $30 million Texas plant.

Productive capacity for zirconium tetrachloride will be increased by 40%, and capacity for silicon tetrachloride by 20% at Stauffer Chemical's Niagara Falls plant. Stauffer is doing its own engineering and construction, should be on-stream with the units by June. □

Olin Mathieson is building a $1.5 million anti-freeze plant at Mapleton, Ill. Plant will be owned and operated for Olin Mathieson by Mapleton Industries, Inc., will be completed by spring 1958. □

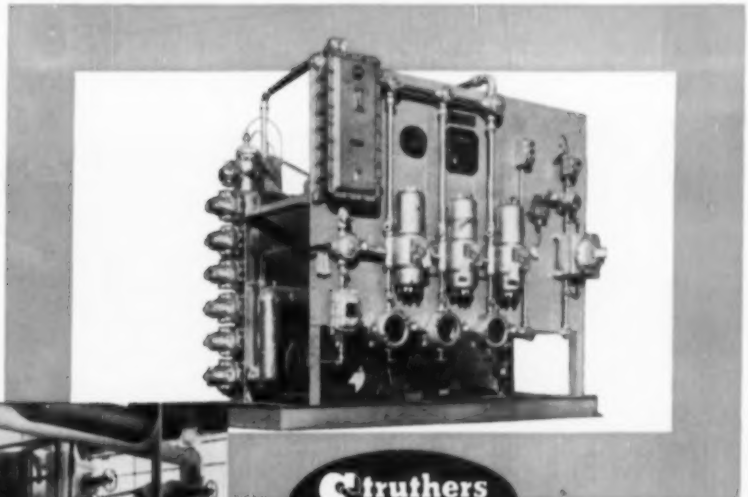
A multi-million pound a year dichloroisocyanuric and trichloroisocyanuric acids plant is being constructed at Everett, Mass., by Monsanto. The plant, first of its kind in this country, is designed for continuous production of the two chemicals, is expected to be operating this fall. □

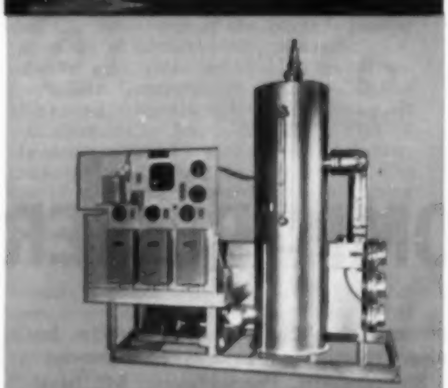
A major expansion in production capacity for phthalic anhydride has been completed at Monsanto's Everett, Mass., plant. Increase is by 60%. □

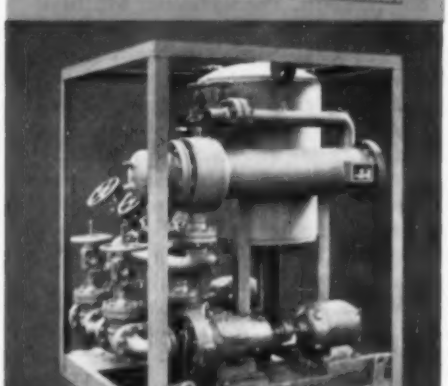
Construction will begin this summer on a gas treating and sulfur recovery plant at American Oil Co.'s Yorktown, Va., refinery. Engineer and builder will be The Fluor Corp., Ltd., and the unit will be designed to remove 50 tons of sulfur each day. □

A contract for the complete design, engineering, procurement and supervision of a tall oil distillation plant has been awarded to Badger Manufacturing Co., Cambridge, Mass., by the Organic Division of Monsanto. The new plant will be located at Nitro, W. Va., is scheduled for completion in the spring of 1958. □

A new $3 million plant for the production of organo-tin chemicals used in vinyl plastics, transformer oils, biocidal and fungicidal agents, and other end products, will be built by Metal & Thermit Corp. in Carrollton, Ky. Production of organic compounds of other metals such as zinc and cadmium is planned for the future. Completion is expected by December, start-up by January 1958. □







Struthers Wells

High Temperature Heating

by Circulating Medium

Struthers Wells supplies circulating heating equipment for a wide range of temperatures and sizes. Many smaller units can be supplied as a "package," completely assembled and ready for operation.

The units illustrated show three electrically heated units for Dowtherm and other fluids, for capacity to above 1,000,000 BTU per hour. Also shown is a circulating cooling unit, (lower left side illustration).

Struthers Wells can supply standard units for capacities from 100,000 BTU per hour to about 40,000,000 BTU per hour. Temperatures range from about 350°F to above 1500°F.

Fired heaters for a wide range of services, including steam superheating, oil and gas heating are also a Struthers Wells specialty. Hundreds of units are in successful service.

If you require heat above the temperature range of available steam pressures, Struthers Wells engineering experience and facilities are always available.

Struthers Wells

STRUTHERS WELLS *Corporation*

WARREN, PA.

Plants at Warren, Pa. and Titusville, Pa.

Offices in Principal Cities

Struthers Wells Products

PROCESSING EQUIPMENT DIVISION

Crystallizers . . . Direct Fired Heaters . . . Evaporators . . . Heat Exchangers . . . Mixing and Blending Units . . . Quick Opening Doors . . . Special Carbon and Alloy Processing Vessels . . . Synthesis Converters

BOILER DIVISION

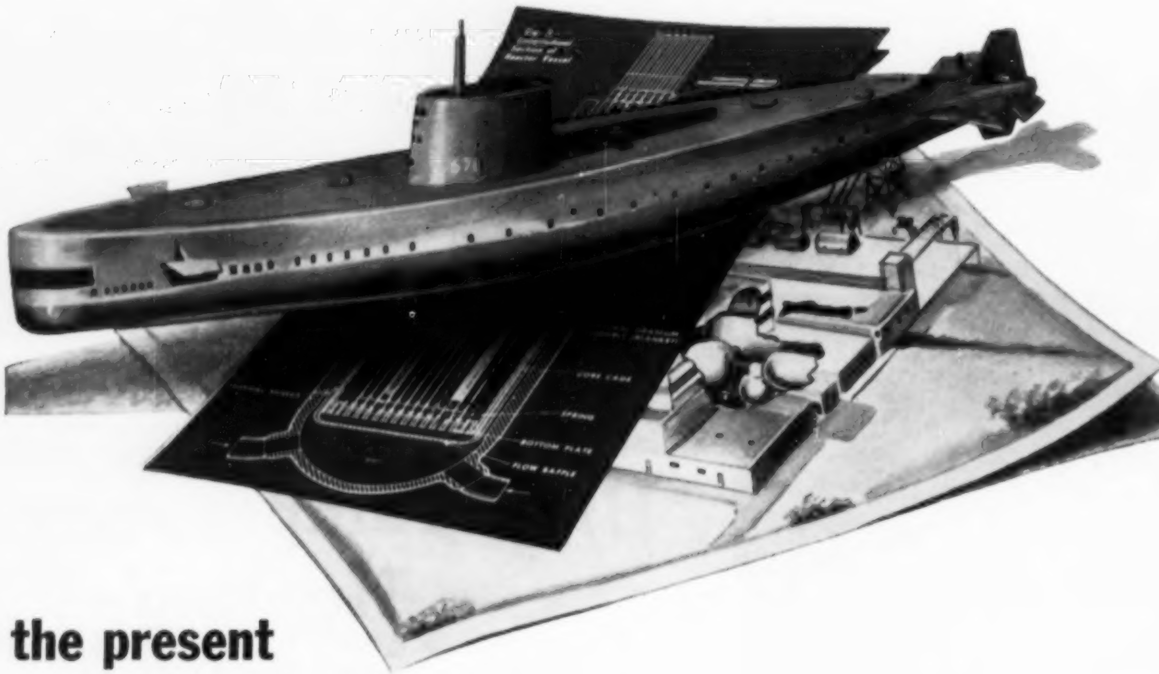
BOILERS for Power and Heat . . . High and Low Pressure . . . Water Tube . . . Fire Tube . . . Package Units

FORGE DIVISION

Crankshafts . . . Pressure Vessels . . . Hydraulic Cylinders . . . Shafting . . . Straightening and Back-up Rolls

MACHINERY DIVISION

MACHINERY for Sheet and Structural Metal Forming . . . Tangent Benders . . . Folding Machines . . . Roller Table and Tumble Die Bending Machines . . . Press Brakes . . . Punching and Notching Machines . . . Forming Dies



the present

and

YOUR FUTURE IN ATOMIC POWER

If you are an outstanding young engineer looking toward a future in Atomic Power, you will be interested in our unique doctoral fellowship program.

The University of Pittsburgh and the Westinghouse Electric Corporation, in cooperation with the Atomic Energy Commission, offer an educational program that permits selected college graduates under a combination work-study program to earn a Doctor of Philosophy in mechanical or chemical engineering with special opportunities for study in nuclear reactor engineering. In addition, the doctoral candidate will have a year's educational leave with a living allowance to prepare his doctoral dissertation.

At Bettis Plant engineers are investigating new areas for progress in all phases of reactor theory, design, and development. Here scientists and engineers have pioneered the first successful application of nuclear power, the USS *Nautilus* prototype. In 1957 the nation's first full-scale commercial generating plant at Shippingport, Pennsylvania, will have its turbines powered by a Westinghouse reactor.

ENGINEERS are needed to solve unusual thermal and stress problems in reactor design and development of power plant auxiliaries. Extensive theoretical and experimental investigations into heat transfer under steady state and transient conditions are necessary to determine reactor design parameters. Previous atomic experience is not required.

If you are interested in working in the expanding field of nuclear power, write today for a detailed brochure on our engineering fellowship program. Address your résumés to: Mr. M. J. Downey, Westinghouse Bettis Plant, Dept. A-162, P.O. Box 1468, Pittsburgh 30, Pennsylvania.

BETTIS ATOMIC POWER DIVISION

Westinghouse

ACRYLONITRILE, ACRYLIC FIBER EXPANSIONS

Two acrylonitrile producers announce large expansions of capacity—an acrylic fiber manufacturer expands production.

The outlook for acrylic synthetic fibers took an optimistic turn this month as Monsanto announced it will increase its output of acrylonitrile to 100 million pounds annually, and Carbide & Carbon Chemicals indicated that its production at Institute, W. Va., will be doubled by the second quarter of 1958. At the same time, Chemstrand plans to enlarge its Acrilan acrylic fiber capacity 50% by the first quarter of 1958.

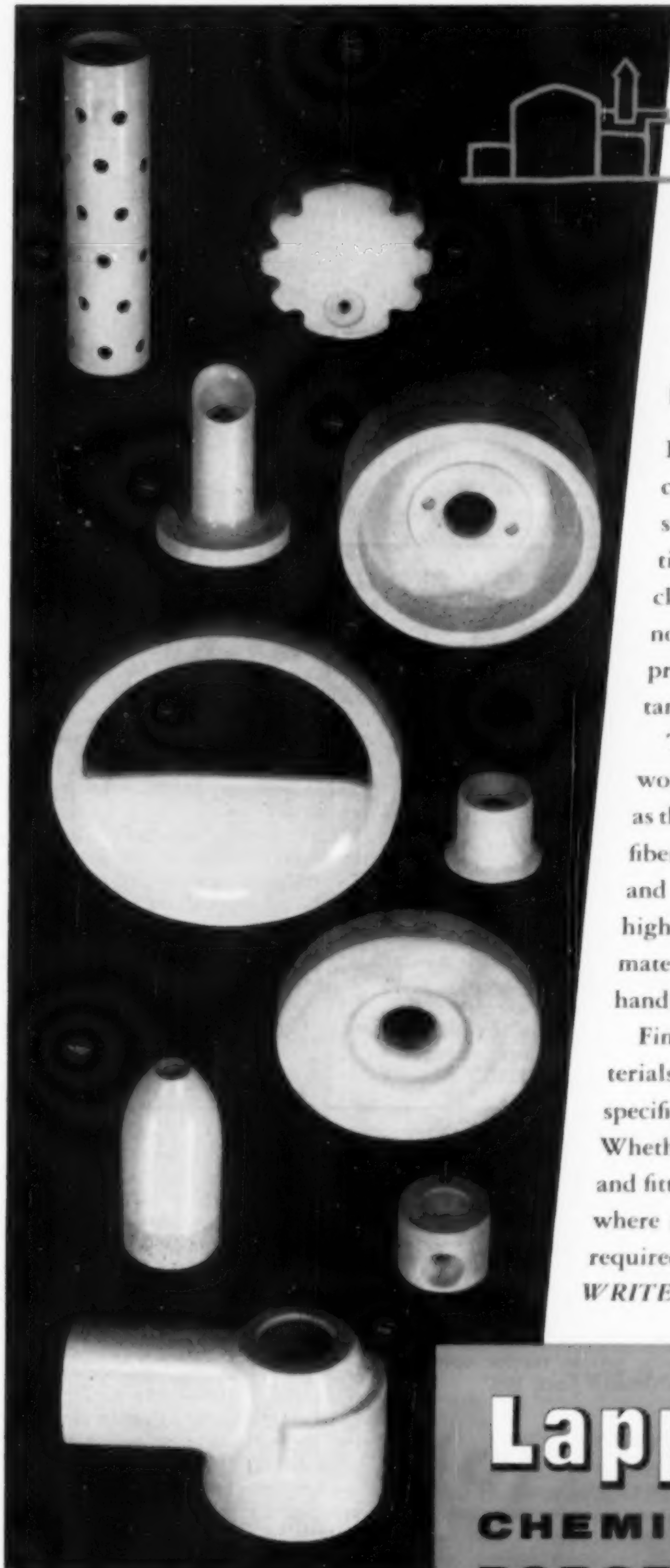
The Monsanto expansion at its Texas City plant will go in large part to Chemstrand for the production of acrylic fiber. (Chemstrand is jointly-owned by Monsanto and American Viscose.)

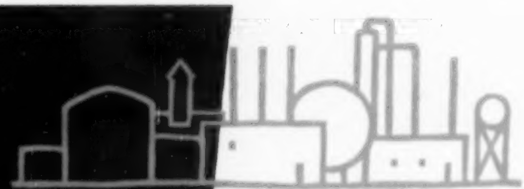
But acrylic fiber is only one of the end products of acrylonitrile. Another major use is its cold polymerization with butadiene to give a Buna-N rubber. A basic plastic raw material, acrylonitrile may soon find wide use in the production of new thermoplastic terpolymers in which it is combined with butadiene and styrene to give polymers with high-impact and high distortion strength. The recent major new butadiene plant (see p. 58) in Texas has sharply increased the potential for these new polymers with acrylonitrile.

Main market for acrylonitrile is still undoubtedly acrylic fibers, where the demand for their use in clothing, blankets, carpeting, and special industrial uses is growing rapidly. Two new derivatives of acrylonitrile (dimethylamino propylamine and diethylamino propylamine) are finding increasing use in the manufacture of textile softeners.

The expansion at Chemstrand will bring that company's annual production of acrylic fiber at Decatur, Ala., up to 45 million pounds.

A new firm to carry out the design, procurement of equipment and materials, and erection of chemical plants and facilities, has been established by Davison-Kennedy Co., Atlanta equipment manufacturing firm. The new firm will be known as Davison-Kennedy Associates and will function independently of Davison-Kennedy Co. Heading the new firm are two former Blaw-Knox engineers. □





LAPP CHEMICAL PORCELAIN FOR ACID AND ABRASION RESISTANT SURFACES

Because Lapp Chemical Porcelain is chemically inert, it is corrosion resistant and ideally suited for handling acids of all concentrations. It is pure, dense, hard, homogeneous, close-grained and non-porous so there can be no penetration—no crumbling from capillary pressures—no absorption of liquids to contaminate later processing.

The hardness of Lapp Porcelain proves its worth when used as a "running surface" such as thread guides or rolls for processing synthetic fibers or sheet stock . . . it cannot be scratched and raise a "burr." Since Lapp Porcelain is highly abrasion resistant, it becomes an excellent material for piping to carry off fly-ash; or for handling cement, pigments and abrasive slurries.

Finally, Lapp Porcelain uses low cost raw materials . . . it can usually be fabricated to customer's specifications for considerable dollar savings. Whether it be special sleeves, nozzles, tubes, pipes and fittings, trays, plates, grates or any other parts where acid and/or abrasion resistant surfaces are required, look to Lapp Chemical Porcelain.

WRITE for description and specifications. Lapp Insulator Co., Inc., Process Equipment Div., 431 Wendell St., Le Roy, N. Y.

Lapp
CHEMICAL PORCELAIN

NEW DEVELOPMENTS TO FOSTER POLYURETHANE GROWTH

Two recent changes in the field of the polyurethanes will encourage expansion of this relatively new plastic.

- **DuPont drops all royalty requirements.**
- **Wyandotte plans production of polyethers.**

While there are definite indications that the polyurethane foams and coatings have not been advancing as fast as had been expected in the plastics industry (see "The Future for Plastics," Roger Williams, Jr., *CEP*, April 1957, p. 100), two new developments will undoubtedly give increased impetus to their growth.

No Royalties

Firms licensed under DuPont's isocyanate patents to make urethane foams and coatings will no longer be required to pay royalties under a new policy announced by the company.

Over 100 licensees, who had been paying 1½% royalty on the selling price of urethane products, will now pay nothing. The new policy is designed to stimulate and encourage the industry.

New Products, New Plant

Wyandotte Chemicals expects to give the urethane industry a boost when its planned new polyether plant comes on stream late this year or early next year.

Importance of the new plant rests in the fact that Wyandotte's already-field-tested polyethers offer improved product life and lower manufacturing costs for products embodying urethane plastics. The polyethers, in fact, threaten to displace the older polyesters used in the manufacture of urethane foams. But new polyesters are being developed, will give the polyethers a battle for this market. The potential advantage of the polyethers as far as cost is concerned will certainly be enhanced by Wyandotte's recent price decrease.

Located at Wyandotte, Mich., the new plant will be known as the oxide products plant, will have a large capacity of millions of pounds annually. Designed for future expansion, the plant will be multi-purpose and capable of increasing output of Pluronic and Tetronic polyols.

Long used as nonionic surfactants, the three major polyethers to be produced by Wyandotte have only recently become important as intermediates in the polyurethane foam market. Wyandotte is not resting on the three now ready for production, is working on others which it expects to announce as available within the next few months.

ALLIED ENTERS LOW PRESSURE POLYETHYLENE PIPE RACE

Pipe made from new high-molecular weight material said to be entirely free from long-term stress cracking.

If all claims for the recently announced A-C polyethylene pipe compound are substantiated in commercial practice, Allied Chemical may turn out to be a strong contender in the race to produce polyethylene pipe which will stand up in chemical plant service. Main stumbling block up to now has been long-term stress cracking, insufficient resistance to hydrocarbon oils and organic solvents. Allied says that the problem has now been licked by development of a high molecular weight polymer (average molecular weight more than 750,000). Details of the low-pressure process used have not yet been disclosed.

Commercial quantities of pipe are already being made by the Orangeburg Manufacturing Co., whose fabricating plants in N. Y. and Calif. are expected to absorb a major part of Allied's 1957 production.

High bursting strength, superior temperature resistance, and absence of stress cracking would indicate application in the petroleum and chemical fields as well as in water supply systems. Irradiation is not necessary, Allied says, since the product will stand boiling water at low pressures, and will stand temperatures up to 150° F. at ordinary working pressures.

(*Continued on page 66*)

NUCLEAR FUEL REPROCESSING—NEW AEC POLICY

Will the AEC's latest action on chemical reprocessing contracts fulfill its ostensible purpose of providing a stable price on which present and prospective reactor owners and operators can base their estimates of operating costs? Will this action discourage potential investment of private venture capital in the fuel reprocessing field?

AEC has recently announced that, until private facilities are in a position to handle the job, it will undertake to contract for reprocessing of fuels from private reactors, presumably in an AEC-owned and operated reprocessing plant. Standard daily processing charge has been set at $15,300, subject to adjustment for various types of fuel elements, etc. The proposed AEC plant is estimated to cost $20,570,000 to construct, yearly operating costs are estimated at $4,592,000, including amortization.

Capacity of the proposed AEC plant is assumed at 1 ton per day of natural or slightly-enriched uranium. Contracts with private reactor operators will run through June, 1967.

Limited Capacity Needed

Based on the power reactors presently under construction or projected in the near future, approximate calculations indicate that the total fuel reprocessing capacity needed will be somewhat less than one half ton per day. These figures were confirmed by *CEP* in an interview with W. K. Davis, Chief of Reactor Development, AEC. According to Mr. Davis, one large plant, such as that envisaged by the AEC, could handle all fuel reprocessing needs for years to come.

Who Will Build the Plant?

The dilemma confronting the AEC is clear—on the one hand, their stated policy is to encourage the participation of private industry in every phase of the nuclear power program; on the other hand, it seems improbable that smaller reprocessing units built and operated by private companies could match the economy inherent in one large central plant. An early decision is indicated as to who will erect and operate the necessary facilities—the Government or the chemical industry.

POLYETHYLENE PIPE

(Continued from page 64)

Welding

Interesting sidelight is a hot welding system said to be in development stage at Orangeburg Manufacturing. Plan is to incorporate welding coils in the fittings themselves. To make a field weld, it will only be necessary to hook up a battery to the coil.

Allied's price for the new compound was not divulged. However, representatives of Orangeburg Manufacturing say that the pipe is cheaper than PVC pipe on the basis of equal working pressures.

MAJOR SULFURIC PLANT

New contact type sulfuric acid plant goes on-stream at Le Moyne, Alabama, is evidence of continued growth of chemical industry in the South.

Designed to service the chemical industry of the Mobile area, the new sulfuric acid plant of Consolidated Chemical Industries, a division of Stauffer Chemical Co., is of the contact type, has a capacity of 500 tons a day.

View of CCI's recently completed and now on-stream sulfuric acid plant at Le Moyne.

The large-scale growth of the chemical industry in the south has led CCI to build this and four other sulfuric acid plants (at Houston, Baytown, Corpus Christi, and Baton Rouge) to serve the increasing needs.

The Le Moyne plant is of the latest design, will furnish sulfuric in all strengths via tank car, tank truck, and barge.

A multi-million-dollar air liquefaction plant will be built at Acton, Mass., by Air Reduction Sales Co., a division of Air Reduction Co. Located near Boston, the plant will produce liquid oxygen, nitrogen, and argon. Capacity will be 75 tons a day overall. □

INDUSTRIAL NEWS

The giant towers of Cosden Petroleum's refinery at Big Spring, Tex., are a scenic sight on the flat Texas plain. Finished with resistant silicone-aluminum, it is painted in silver and gold with red, green, and black trim.

SODIUM BOROHYDRIDE FOR GOVERNMENT

In the second of two contracts with Metal Hydrides, Inc., the U. S. Government contracts to buy output of plant now under construction.

For its high-energy fuel program, the Government has contracted for the delivery of sodium borohydride valued at $9,200,000. Producer will be Metal Hydrides and the delivery will cover an 18 month period.

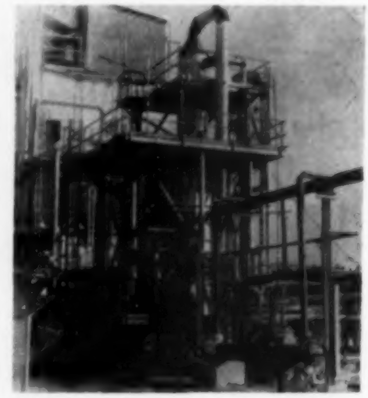
This is the second of two contracts. Under the first contract, Metal Hydrides furnished land, site improvements, rail sidings, and all buildings for a plant capable of tonnage production of sodium borohydride. The Government is paying for the acquisition and installation of all equipment in the plant at an estimated cost of $4,400,000.

The plant is now under construction in Danvers, Mass. It is scheduled to be on stream in October.

A new ethanolamines unit that more than doubles the ethanolamines capacity of Union Carbide Chemical is now on-stream at the company's Seadrift, Texas, plant. □

Plans for the construction of a $5 million chemicals plant near Henry, Ill., have been announced by B. F. Goodrich Chemical Co. The plant will produce specialty organic chemicals such as anti-oxidants for use in petroleum, rubber, plastics, and other industries. Completion is scheduled for early 1958. □

INDUSTRIAL NEWS



This 120-inch diameter ammonium nitrate neutralizer is in service at the Mississippi Chemical Corp. plant at Yazoo City, Miss. The extremely low carbon content of the grade of steel used prevented harmful carbide precipitation during fabrication and erection by Vulcan Manufacturing Division, Vulcan-Cincinnati, Inc.

Expansion programs at Naugatuck Chemical Division's (U.S. Rubber) Baton Rouge installation will cost $9 million when all completed. One facet of the expansion is the 60% increase in production of Paracril oil-resistant synthetic rubber that has just been completed. The second is the new Kralastic plastic materials plant now going up. This new plant will triple the company's production capacity for Kralastic, bringing the total of plastic and synthetic rubber to 60 million pounds a year. □

The largest catalytic reforming unit in the world has just gone on stream at Tidewater Oil's new Delaware City refinery. The unit is a 45,000 bbl. a day Houdriformer. The giant unit, constructed by C. F. Braun & Co., will be operated on a wide range of feedstocks, predominantly naphthas from Middle East crudes. □

A new sodium silicofluoride plant, costing more than $750,000, is now in full production at Pasadena, Texas. Built by Olin Mathieson Chemical Corp., the new unit recovers fluorides from phosphoric acid manufactured at the adjoining fertilizer plant of the company's Plant Food Division. □

Construction of a second synthetic glycerine plant is under way at Dow Chemical's Texas Division in Freeport, Texas. Completion, scheduled for March 1958, will double Dow's glycerine capacity. The second plant will use the same Dow developed process involving propylene and chlorine as starting materials. □

READY ANSWER

to 1001* process heating and cooling problems

ROSS

* No one has made a recent check to determine just how many process heating and cooling assignments are taken on by standard Ross Exchangers. There may be more than a 1001, or even a few less. But this much *is* known . . .

Standard Ross Exchangers are engineered and constructed to cope with the *unusual* as well as the routine jobs in chemical processing. There are so many types and sizes, so many kinds of materials, so many alternate features available . . . it's hard to name a condition they don't meet.

Think of all the delays and costs that are spared in this way! With several designs pre-engineered and fully standardized in a large range of graduated sizes, units are readily assembled from mass produced parts and sub-assemblies in relatively no time at all . . . for each application. What could be simpler?

And when standard units cannot fill the bill *precisely for all conditions*, slight modifications often do the trick. Many a process problem has been successfully solved by Ross this way, too.

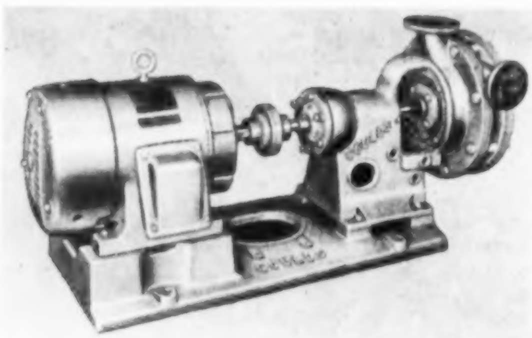
But why concern yourself with the problem at all? That's a job for Ross engineers. They're doing it for others, and can do it for you. Let Ross determine whether *your* needs call for standard, modified standard, or specially engineered units. Yes, let Ross do it, because Ross designs and builds all three!

Write Ross Heat Exchanger Division of American-Standard, Buffalo 5, N. Y. In Canada: American-Standard Products (Canada) Limited, Toronto 5, Ont.

ROSS HEAT EXCHANGER

Division of AMERICAN-Standard

CEP Data Service



DEVELOPMENTS OF THE MONTH

388 Glassed Centrifugal Pumps. Designed for handling corrosive liquids in the chemical processing and allied industries.

The new pump is the result of engineering collaboration between the Pfaudler Co. and Goulds Pumps, Inc.

The pump is said to have extremely high resistance to practically all acids and alkalies. It is resistant to thermal shock and will normally withstand quick changes in temperature of the liquid handled up to at least 200° F. differential.

Goulds Pumps, Inc. offer a detailed catalog on the Goulds-Pfaudler pumps. Included are cross section drawings, materials of construction, specifications and performance curves. For further information, circle number 388 on Data Post Card.

ENGINEERING DATA—EQUIPMENT

301 Electric Heaters and Heating Devices. 72-page publication from General Electric includes 16-page power requirements section, showing short and long form calculations for heating applications.

302 Pneumatic Pressure Regulator and Shutoff Valve. Reduces high-pressure gas at 3,000 lb./sq.in. to predetermined lower outlet pressure. Garrett Corp.

303 General Purpose Digital Computer. Bulletin from Bendix Computer Division of Bendix Aviation describes low-cost accessory that enables Model G-15 to operate as a digital differential analyzer.

304 Hydraulic and Pneumatic Control Catalog. Bulletin from Barksdale Valves gives details on complete line of manual, solenoid, pilot-controlled valves, pressure switches.

305 Supersensitive Oxygen Indicator. Can measure as little as two parts per million of oxygen in hydrogen or inert gases despite presence of up to three per cent carbon monoxide. Baker & Co.

306 Mass Produced Nuclear Reactor. The AGN 201 Reactor, produced by Aerojet-General Nucleonics, is available for immediate delivery. Descriptive bulletin.

307 Dry Chemical Weigh Feeder. Material flow through machine is electronically controlled. Accuracy to within 1 per cent. Complete specifications available from Syntron Co.

308 Blending Systems. For all processes requiring fine powder blends of high uniformity. Bulletin from Sprout, Waldron & Co.

309 Glass Protected Steel Smokestacks. Said to offer 3 to 5 times longer protection against corrosion. Bulletin from A. O. Smith Corp.

310 Rotary and Hydraulic Pump Catalog. Also booklet "How to Solve Pumping Problems." Geo. D. Roper Corp.

311 Meter, Regulator and Valve Catalog. Condensed 28-page catalog from Rockwell Manufacturing Co.

312 Mechanical Seal Catalog. An engineered mechanical seal that rotates with

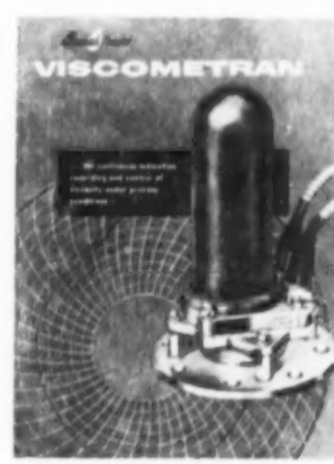
(Continued on page 78)

DEVELOPMENTS OF THE MONTH (*Cont.*)

389 Viscometer Catalog. Brookfield Engineering Laboratories offer catalog giving complete information on application of the Brookfield Viscometran for continuous in-process viscosity measurement and control.

The Viscometran is based on the same principle as the Brookfield "Synchro-Lectric" Viscometer. A cylinder or other appropriately shaped spindle is rotated at a constant speed in the liquid under test. The torque required to produce this rotation is directly proportional to the centipoise viscosity of the fluid. The Viscometran transmits a viscosity signal to a suitable receiver by sending an electrical impulse proportional to the torque required to rotate the spindle.

The instrument is said to be suitable for a wide range of materials of both Newtonian and non-Newtonian types. Temperature extremes offer no problem since the Viscometran need not be near the test material. Practical working temperature is limited only by the melting point of the spindle used. Corrosion protection is assured since the spindle can be furnished in a variety of plastic or alloy materials. For further information, circle number 389 on Data Post Card.



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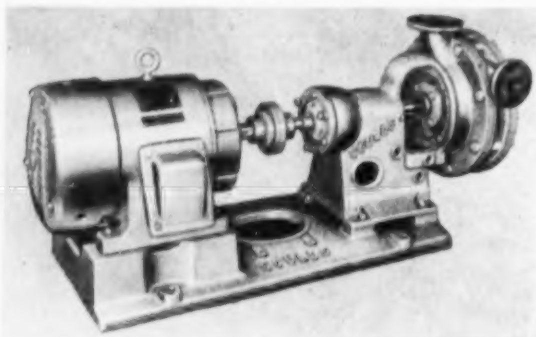

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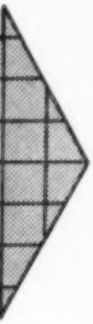
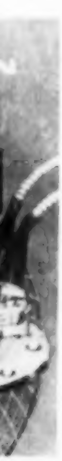
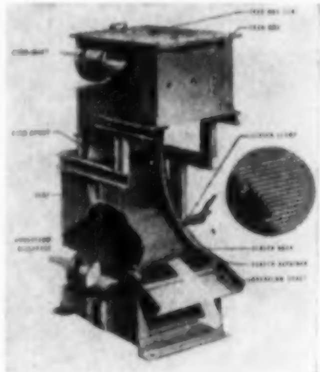




DEVELOPMENTS OF THE MONTH (Cont.)



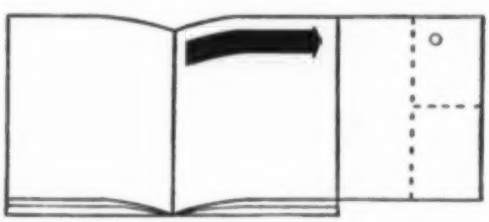
390 Screen for High Capacity Separation. Dorr-Oliver Inc. announces availability of the DSM Screen for continuous wet screening of slurries containing non-fibrous solids. It is said to be particularly adaptable to separation in the 8 to 48 mesh range and to have capacity and efficiency far beyond that of vibrating screens.

The unit is available in four standard sizes ranging in width from one to four feet in increments of one foot. Capacity is approximately 200 gallons per foot of width per minute when making a 48 mesh separation and as high as 500 gallons per foot per minute in producing an 8 mesh separation. In all units, the screen, as it wears, can be reversed to obtain the desired separation and to maintain uniform wear across the face. For complete technical details from the manufacturer, circle number 390 on Data Post Card.

(Continued on page 75)

JUST A MOMENT is needed to learn how to use this insert. When looking through the front part of the magazine, pull the folder portion of the insert out to the right, and the numbers on the post card are convenient for circling.

THEN . . .



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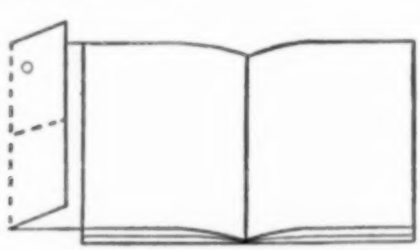

Numbers followed by letters are for checking your interest in the products, equipment, and services advertised in this issue, the number corresponding to the page on which the ad appears. Letters indicate position on the page: L, Left; R, right; T, top; B, bottom. A indicates a full page; IFC, IBC, and OBC are cover advertisements. **Numbers in the 300-series** bring you new engineering data in the chemical engineering field.

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32-33A 34A 35A 37A 38L 39A 40-41A 42L 43-44A
45A 46A 47R 48A 49A 50B 51A 52L 53A 54A
56A 208A 57A 59A 60A 61A 62L 63A 65A 66L
67A 68L 69A 70L 71A 72A 77A 79A 81A 83A 85A
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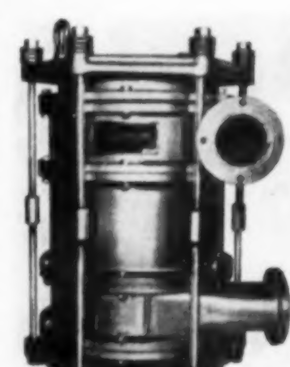
391 Centrifugal Dust Separator. A new low-cost, high efficiency centrifugal dust separator, the "HV," is announced by Day Sales Co. Equipment is completely welded, made of heavy black iron, scientifically designed for maximum efficiency. Path of dust-laden air traveling through the "HV" encounters a minimum of turbulence due to the scroll inlet and airfoil design inlet vane. A steep, smooth cone assures uniform, quick delivery of dust to the dust outlet. Initial cost is reported to be lower than that of many light gauge, galvanized metal cyclones. The range of applications is wide; the unit can handle fibrous, granular, abrasive, fine or coarse dusts at normal or high temperatures under pressure or vacuum conditions. Stainless steel units available if required. For further information, circle number 391 on Data Post Card.

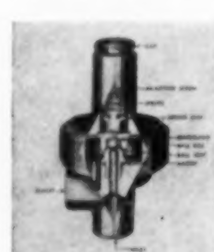
392 Graphite Heat Exchanger. The "Polybloc" is composed of easily interchangeable impermeable graphite blocks, molded to give high thermal conductivity. The blocks have two sets of passages—radial and axial. Heat is exchanged between any two fluids in the same block. The blocks are molded, rather than extruded, so that the graphite particles are in the correct alignment for the greatest thermal conductivity usually taken as a heat coefficient of 87 B.t.u. per hour per sq.ft. per °F. This coefficient is said to be almost equal to that of copper, aluminum, and red brass, and to be considerably better than that of extruded graphite, cast iron, stainless steel, tantalum, etc.



The manufacturers, the Carbone Corp., offer a bulletin with all technical details on the equipment and extensive tables on its corrosion resistance. For further information, circle number 392 on Data Post Card.

393 Non-Leaking Relief Valve. Developed by the Milton Roy Co. to assure the accuracy of their controlled-volume pumps.

Especially effective for chemical metering systems, these valves have ball checks which provide tight shut-off, non-chattering, snap action, and high volume relief at low pressures. A wide range of pressure settings can be changed with a screw driver, and internal parts can be cleaned or replaced without removing valve from the line.



Constructed of steel, 316 stainless, Carpenter 20, or Hastelloy C, this valve has a diaphragm protecting the spring and top works so that it can be used with corrosive liquids at pressures to 1,500 lb./sq.in. and temperatures to 250° F. For further information, circle number 393 on Data Post Card.

(Continued on page 78)

PRODUCTS ADVERTISED IN THIS ISSUE

IFC Methyl Ethyl Pyridine. Technical data on 2-methyl-5-ethyl pyridine from Carbide and Carbon Chemicals. Samples also available.

3R Rotary Sifter Bulletin. Describes Model "M" Bar-Nun Rotary Sifter, available with from 2 to 76 sq.ft. of screen surface. B. F. Gump Co.

4A Fluid Separation Equipment. Bulletin and complete list of case histories on performance of Yorkmesh Demisters. Otto H. York Co.

6A Diaphragm Control Valve Catalog. Engineering data from Kieley & Mueller, Inc.

7A Mixer Selection Data. Catalog from Mixer Division, Eastern Industries, Inc., describes portable, turbine, and top and side entering mixers.

9A Compressors. Continuous, maintenance-free performance with Cooper Bessemer industrial compressors. Technical details from manufacturer.

10A Design and Construction Services. Brochure from Southwestern Engineering Co. describes their facilities in petroleum, chemical, and ore beneficiation fields.

11A Special Purpose Stainless Steels. 44-page booklet "Making the Most of Stainless Steels in the Chemical Process Industries." Crucible Steel Co. of America.

12L Jobs for Designers. Process, process equipment, mechanical, instrument, power designers wanted by E. I. du Pont.

13A Industrial Mixers. Technical details from Philadelphia Gear Works on their line of Philadelphia Model PTS mixers.

14A Industrial Catalysts. For hydrogenation, synthesis gases, and hydrogen generation, desulfurization, new catalytic processes. Bulletin from Girdler Co.

15A Heavy-Duty Compressors. Air and gas compressors for all chemical processing needs. Ingersoll-Rand.

16A-17A Design, Engineering, Construction. Bulletin from Blaw-Knox outlines scope of company's activities in various process industries.

18L Corrosion-Resistant Packings and Seals. Catalogs from United States Gasket Co. give details of Teflon packings and mechanical seals.

21A Chemical Process Valves. Bronze, iron, steel, and corrosion-resistant valves for every flow control problem. Wm. Powell Co.

25A Liquid Clarifiers. Bulletin from Centrico, Inc. describes Westfalia KG clarifiers for liquid clarification and solids recovery.

27A Pressure Leaf Filters. Process Filters, Inc. offers complete line of pressure leaf filters and accessories for wide range of process conditions. Bulletins.

28L Ball Bearing Swivel Joints. For application from high vacuum to 15,000 lb./sq. in., and from sub-zero temperatures to 750° F. Continental-Emsco Co.

29A Water Conditioning Equipment. Complete details on feeders and other types of water-conditioning equipment available from the Permutit Co.

30A Equipment Fabrication. All types of chemical process equipment in wide range of metals and alloys. Bulletin from Koven Fabricators, Inc.

31A Industrial Filters. Adams filters feature safe cleaning without disassembly by sudden, high velocity reverse flow of backwash liquid. Bulletins from R. P. Adams Co.

32A-33A Standardized Pumps. More than 70,480 combinations from standard stocked parts. Bulletin from Worthington Corp.

34A Indirect-Heat Rotary Dryers. Consulting services, pilot plant tests, estimates without obligation. Louisville Drying Machinery Unit, General American Transportation Corp.

35A Electronic Flowmetering Systems. High accuracy through wide range of temperature, pressure, density, and viscosity conditions. Bulletin from Potter Aeronautical Corp.

37A Mikro-Pulverizers. Available in capacities up to 25,000 pounds per hour. Technical details from Pulverizing Machinery Division, Metals Disintegrating Co.

38L High Pressure Needle Valves. Large or small valves in 416 stainless steel or other alloys to special order. Bulletin from August Spindler & Sons, Inc.

39A Barges for Chemical Transport. Ingalls Shipbuilding Corp. specializes in building barges to your exact specifications and requirements.

40A-41A Process Equipment Bulletin. Covers all Allis-Chalmers equipment for the process industries.

42L Entrainment Manual. Sixteen-page booklet discusses liquid/vapor separation in vacuum and flash towers, absorbers, scrubbers, evaporators, and distillation equipment. Schuyler Manufacturing Corp.

43A-44A Chemical Product Information. U.S.I. Chemical News describes new developments and products of U. S. Industrial Chemicals Co.

45A Molecular Sieve Adsorbents. Descriptive booklet "Molecular Sieves for Selective Adsorption" from Linde Air Products Co.

46A Nickel Alloy Steels. Consulting services on metal difficulties. Write for List A of available publications. International Nickel Co.

47R Spiral Ribbon Mixers. In working capacities from 1 to 500 cu.ft. Complete details from Read Standard Division of Capitol Products Corp.

48A Pneumatic Transmitters. Null-balance-vector design permits 20-to-1 range adjustment without resetting zero. Bulletins from Republic Flow Meters Co.

49A Steam Jet Syphon. Bulletin from Schutte and Koerting Co. describes complete line of SK jet apparatus.

50B Equipment Fabrication. Fractionating towers, tanks, pressure vessels, digesters, etc. Posey Iron Works, Inc.

51A Vinyl Resins. Complete information on "Exon" resins from Chemical Sales Division, Firestone Plastics Co.

52L Heat Exchangers. "Heliflow" exchangers offer many advantages in chemical processing. Graham Manufacturing Co.

53A Vacuum Equipment. "Chill-Vactors," steam-jet evactors, fume scrubbers, special jet equipment. Croll-Reynolds Co. Literature.

54A Non-Pressurized Heat Transfer Systems. Aroclor 1248, a highly stable chlorinated polyphenyl, makes possible non-pressurized liquid-phase heat transfer systems that operate up to 600° F. Technical data from Monsanto Chemical Co., Organic Chemicals Division.

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▶ **GET** *up-to-the-minute catalogs, data sheets and bulletins on new chemical products, processes and equipment.*

56A Cooling Tower Gears. Fluor-Western Gears assure longer life with lower maintenance cost. Fluor Products Co.

208A Nozzle Type Safety-Relief Valves. Adjustable nozzle ring assures sharp, controlled pop action. Details from Crosby Valve & Gage Co.

57A Flexible Plastic Tubing. "Tygon" clear flexible plastic tubing is made in six standard formulations and more than 50 standard sizes. Booklet from U. S. Stoneware Co.

59A Circulating Heating Equipment. Wide range of temperatures and sizes. Many "package" units available. Struthers Wells Corp.

60A Jobs in Nuclear Power. Detailed brochure on engineering fellowship program. Bettis Atomic Power Division, Westinghouse.

61A Inert Gas Generators. Complete facts and technical information from C. M. Kemp Mfg. Co.

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61A Inert Gas Generators. Complete facts and technical information from C. M. Kemp Mfg. Co.

(Continued on page 80)

the shaft. 17-page bulletin from Durametallic Corp.

314 Stainless Steel Rotary Pump. Low-capacity, self-priming positive displacement pump in 304 molybdenum-free stainless steel available from Eco Engineering Co. Capacities to 10 gal./min. and pressures to 75 lb./sq.in.

315 Centrifugal Oil Purifiers. The De Laval Direct Motor Drive Oil Purifier is available in six sizes, with either stationary or portable base. Bulletin from De Laval Separator Co.

316 Portable Mass Spectrometer. Type 21-611 mass spectrometer, produced by Consolidated Electrodynamics Corp., is designed to analyse extremely small amounts of gaseous mixtures. Bulletin.

317 Water and Aqueous Liquid Filters. Booklet giving gal./min., operating pressures, tube lengths, pipe sizes, inlet-outlet sizes, height, and weight of "Fulflo" filters, made by Commercial Filters Corp.

318 PVC Fan. Available in several belt-driven sizes from 12 in. to 40 in. diameter. Capacity from 200 to 10,000 cu.ft./min. Centrifugal, non-overloading, radial-bladed design. Chicago Blower Corp.

319 Dual-Flow Rotary Dryer. Single-sheet bulletin gives design and construction features, other technical details of dual-flow rotary dryer, made by Carpco Manufacturing, Inc.

320 Air Compressor Catalog. Specifications and selection data on line of compressors from ¼ through 20 horsepower. Brunner Manufacturing Co.

321 Resin Bonded Fiber Glass Equipment. Combines strength of steel, lightness of aluminum, corrosion resistance of alloys and vitreous materials. Bulletin from du Verre.

322 Nuclear Reactor Simulator Assembly. Makes vivid graphic demonstration of nuclear reactor kinetics. Semi-portable. Bulletin from Leeds & Northrup Co.

323 Flow Tube Performance Data. Bulletin from Foster Engineering Co. gives performance and calibration curves for "Gentile" flow tubes.

324 Super Pressure Equipment. 100-page catalog describes valves, fittings, reaction vessels, compressors, pumps, complete pilot plant units—all designed for extremely high pressures. American Instrument Co.

325 Automatic Control Valves. Pressure, temperature, and level control valves for every chemical process application. Catalog from Atlas Valve Co.

326 Distilled Water Piping. Tin-lined pipe, fittings, valves, combine the chemical protection of pure tin with strength and durability of threaded pipe. Bulletin from Barnstead Still & Demineralizer Co.

327 Indicating Pneumatic Transmitter. For the precise measurement and transmission of flow, liquid level, differential pressure. Specifications and technical details in bulletin from Barton Instrument Corp.

328 Liquid-Gas Separation Equipment. Continuous, automatic removal of water, water-oil emulsions, and dirt from compressed air and gases is possible with the "Liqui-Jector," made by Selas Corp. of America. Bulletin.

329 Steel and Alloy Equipment. All types of chemical processing equipment in carbon steels, stainless, clads, alloys. Bulletin from R. E. Moyer, Inc.

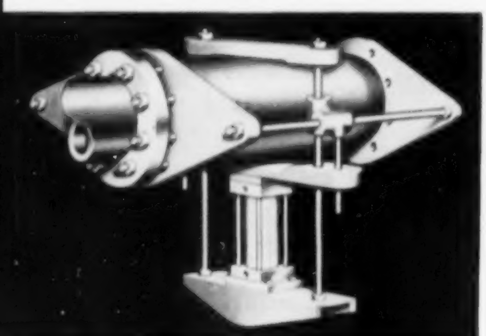
330 Purifier Catalog. Purifiers, mist extractors, scrubbers, steam traps, strainers, for the chemical and petoleum industries. V. D. Anderson Co.

331 Industrial Pump Data. Bulletin from Johnston Pump Co. describes complete line of industrial pumps, heads to 1,200 feet, capacities to 12,000 gal./min., temperatures to 600° F.

DEVELOPMENTS OF THE MONTH (Cont.)

394 Improved Pinch Type Valve. New models of the Massco-Grigsby Pinch Valve are said to incorporate several improvements of value in chemical plant applications.

The valve is specially designed for handling abrasive and corrosive pulps and liquids. It is available with either rubber or neoprene sleeves, in sizes from 1 to 14 inches inside diameter, for pressures to 150 lb./sq.in., and temperatures to 200° F.



Outstanding feature is "Hydral-Air" operating mechanism for easy, fast closing. Can also be equipped for automatic regulation to control liquid level or rate of flow in pipe lines.

Sleeve arrangement forms a perfect seal, eliminates packing glands, and provides straight unobstructed flow. No working parts are in contact with pulp or liquids.

Complete specifications and information on recommended chemical applications available from the Mine & Smelter Supply Co. For further information, circle number 394 on Data Post Card.

(Continued on page 80)

MATERIALS

358 Product and Process Index. 42-page brochure from Union Carbide and Carbon Corp. lists products and processes offered by their divisions and subsidiaries.

359 Rigidized Teflon. "Enflon," a new rigidized Teflon, is said to be relatively stable at 575° F. and to surpass normal Teflon in load, temperature, coefficient of friction and wear resistance. Catalog from Enflo Corp.

360 Corrosion Inhibitor Data. Bulletin from O'Brien Industries, Inc. describes properties of "O'B-Hibit," an inhibitor for use with sulfamic, oxalic, phosphoric, and all sulfate-based acids.

361 Lithium Compound Data Sheets. Compilation of data sheets from the Foote Mineral Co. gives chemical and physical properties of lithium compounds.

362 Heat-Stable Silicone Rubber. "Silastic 916" made by Dow Corning Corp. is said to combine thermal stability and high dielectric properties of silicone rubber with mechanical strength and abrasion resistance of natural rubber. Pilot plant quantities available.

363 Chrome Nickel Cast Iron Alloy Pipe. Specifications, sizes, dimensions, approximate weights of "CNI" pipe, product of Attalla Pipe and Foundry Co. Bulletin.

364 Mechanical Packings Brochure. Crane Packing Co. offers brochure on chemically-inert mechanical packings fabricated from DuPont Teflon.

365 Industrial Chemicals. 21-page booklet from the Harshaw Chemical Co. lists wide range of industrial chemicals made by the company.

366 Glycol Data Folder. Fifteen easy-to-read charts showing physical properties of interest to users of diethylene and triethylene glycols. Carbide and Carbon Chemicals Co.

367 New Boron Chemicals. American Potash & Chemical Corp. announces production of boron trichloride and boron tribromide.

368 Aluminum Corrosion Guide. Many graphs showing yearly corrosion rate of

(Continued on page 80)

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▶ **GET** *up-to-the-minute catalogs, data sheets and bulletins on new chemical products, processes and equipment.*

MATERIALS (Cont.)

more than 100 chemicals and other corrosive materials on aluminum. Reynolds Metals Co.

369 Surface Active Agent from Sugar. Technical data sheet on "Sucrodet D-600," said to be the first surface active agent from sugar, offered by Berkeley Chemical Corp.

370 Silicon Data. 20-page monograph, "The Relation of Silicon and its Properties to the Electronics Industry," offered by Aries Laboratories, Inc.

371 Teflon Resin-Glass Fiber Pipe. Four-page bulletin from Resistoflex Corp. gives specifications of "Fluoroflex-T pipe—a chemically inert, fracture-proof pipe processed from Teflon resin and glass fiber.

372 Impervious Graphite Selection Guide. Expanded bulletin from National Carbon Co. gives recommendations for application of "Karbate" impervious graphite and "National" resin base cements.

373 Surface Active Agent Bulletin. Technical data on the seven types of "Aerosol" surface active agents offered in commercial quantities by American Cyanamid.

374 Seamless & Welded Pipe Catalog. In carbon, alloy, & stainless steels. Dimensions, weights, specifications, grades, analyses. Babcock & Wilcox Co.

375 High Purity Dicyclopentadiene. Complete new technical bulletin with characteristics and reactions available from Enjay Co.

376 Pipe and Block Insulation. "Thermasil," product of Ehret Magnesia Manufacturing Co., is a hydrous silicate compound, blended with other selected inorganic materials reinforced with long asbestos fibers. For temperatures up to 1,200° F. Literature.

377 Nonionic Surface Active Agents. Data sheets from Industrial Chemicals Division of Olin Mathieson Chemical Corp. give properties of new "J" series of nonionic surface active agents.

378 Zirconium and Hafnium Booklet. Twelve-page booklet from U. S. Industrial Chemicals Co. gives mechanical and physical properties.

379 Isophthalic Acid Alkyds. Complete descriptions and detailed specifications in brochure from Reichhold Chemicals, Inc.

SERVICES

381 Welding and Metallizing Services. Two descriptive bulletins from Protective Coatings Division of Metalweld, Inc.

382 Engineering and Construction Services. 28-page brochure from Blaw-Knox Co. describes complete engineering and construction services offered by its Chemical Plants Division to the petroleum industry.

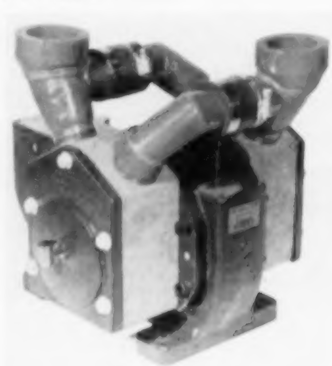
383 Nuclear Reactor Training. Brochure from Daystrom Nuclear describes their extensive new educational facilities at West Caldwell, N. J.

384 Ultrasonic Welding. Bulletin from Aeroprojects Inc. gives details of ultrasonic equipment for joining similar or dissimilar metals by the introduction of vibratory energy.

385 Chemical Disposal Service. Industrial By-Products & Surplus Co., Division of Aceto Chemical Co., announces new service for disposal of accumulated unwanted chemicals.

DEVELOPMENTS OF THE MONTH (Cont.)

395 Duplex Replaceable-Lining Pump. Vanton Pump & Equipment Corp. announces availability of new 40 gal./min. duplex "flex-i-liner" pump. The duplex pump maintains all of the basic features of other Vanton pumps in that there are no stuffing boxes or shaft seals. The fluid is in contact only with the outer surface of the replaceable flexible liner and the inner surface of the housing. A rotor, mounted on an eccentric shaft within the flexible liner, progressively pushes the fluid about its outer surface.



The pump has two fluid cavities, each activated by an eccentric 180° in opposition, allowing a balanced fluid flow free of pulsation. It is driven through a built-in gear reduction located between the two fluid ends. Therefore, while the motor speed is 1,800 rev./min., the pump shaft speed is 1,200 rev./min.

The pump is self-priming and will handle corrosive liquids, gases, abrasive slurries, pharmaceuticals, or viscous fluids. Complete catalog available. Circle number 395 on Data Post Card.

(Continued on page 82)

386 Nuclear Research and Design. Advanced Scientific Techniques Research Associates (Astra) offer brochure describing their nuclear research and design facilities.

387 Nuclear Design and Construction. Brochure titled "Nuclear Power Facilities and Activities" reviews role of Combustion Engineering, Inc. in the nuclear field.

PRODUCTS ADVERTISED IN THIS ISSUE (Cont.)

62L Vertical Industrial Pumps. Capacities from 20 to 3,000 gal./min. Heads to 600 lb./sq.in. Bulletin from Layne & Bowler Pump Co.

63A Chemical Porcelain Products. Special sleeves, nozzles, tubes, pipes and fittings, etc. Description and specifications from Lapp Insulator Co.

65A Particle Classification Equipment. "Super-D-Canter" and "DH-3 Nozljector" for wet classification; "Super Classifier" and "Micromerograph" for dry powders. Sharples Corp.

66L Rotameters. SK "Safeguard" Rotameters now available with PVC end fittings for corrosive service. Bulletin from Schutte and Koerting Co.

67A Industrial Blowers. Engineering services on any product or process application offered by Roots-Connersville Blower.

68L Vacuum Mixers. Details on line of chemical mixing machinery from Baker Perkins, Inc.

69A Silica Gel. Wide variety of particle sizes, densities, and adsorptive capacities. Technical data from Davison Chemical Co.

70L Vertical Bayonet Vaporizers. Two types: general purpose for propane or butane; heavy duty for refinery or chemical plant use. Richard M. Armstrong Co.

71A Standardized Heat Exchangers. A ready answer to many process heating and cooling problems. Ross Heat Exhanger Division of American Standard.

72A Process Equipment Fabrication. Design and fabrication in all ferrous and non-ferrous metals. Acme Coppersmithing & Machine Co.

77A Spray Dryers. Bowen Engineering, Inc. offers consulting services on any spray drying problem.

79A Specially-Engineered Expansion Joints. Adsco expansion joints said to be superior to pipe bends because of less heat loss, less pressure drop, less space, less cost. American District Steam Division, Yuba Manufacturing Co.

81A Chromium Stainless Steels. Types 405, 4110, and 430 stainless plate available on quick delivery from G. O. Carlson, Inc.

83A Teflon Pump. Eight-page catalog from Vanton Pump and Equipment Corp. tells whole story of new Teflon pump.

85A Equipment Fabrication. Sun Shipbuilding & Dry Dock Co. offers help in overcoming any problem of construction or shipment.

86L Corrosion-Resistant Rotary Pumps. New rotary pump, made by Eco Engineering Co., uses fluid Teflon shaft seal. Literature.

87A Impervious Graphite Data. Technical data on "Karbate" impervious graphite

(Continued on page 82)

PRODUCTS ADVERTISED IN THIS ISSUE (Cont.)

equipment and "National" resin base cements. National Carbon Co.

88L Steam Jacketed Flexible Ball Joints. Available in 2, 3, 4, and 6 in. sizes. Catalog from Barco Manufacturing Co.

89A Plant Design and Construction. Hydrocarbon processing plants, gas producing plants, chemical plants, specialty catalysts. Girdler Co.

91A Tubing for Heat Transfer Equipment. Bulletin from Babcock & Wilcox Co. gives technical data on B&W electric-resistance-welded carbon steel tubing.

92L Oil Reclaimer Systems. Will maintain oil free of all solids, sludge, acid, moisture, solvents, and dissolved gases and restore viscosity and dielectric strength. Bulletin from Hilliard Corp.

93A Custom-Built Filters. The Eimco Research and Development Center is at your service for solution of individual filtration problems. Eimco Corp.

94L Tank Vents and Flame Arrestors. For maximum protection of volatile liquids in storage. Black, Sivalls & Bryson, Inc. Catalog.

95A Design and Construction Services. New Badger-built plant for Cosden Petroleum Corp. uses new process to make styrene directly from gasoline. Brochure from Badger Manufacturing Co.

96L Teflon Products Bulletin. Describes full line of Teflon sheet, rod, and tubing. Crane Packing Co.

97A Magnetically Agitated Autoclave. The "Magne Dash" autoclave, made by Autoclave Engineers, is ideal for small batch research work. Pressures to 5,000 lb./sq.in.

98L Air Drying Equipment. Bulletins from Niagara Blower Co. describe the controlled humidity method using "Hygrol" moisture-absorbent liquid.

99A Corrosion-Resistant Pumps. Series H Durcopumps available in Durimet 20, 300 series stainless steels, and 11 other standard alloys. Details from the Duriron Co.

100L Flexible Metal Hose. In bronze, carbon steel, and Monel with standard or special fittings. Bulletin from Packless Metal Hose, Inc.

101A Industrial Crystallizers. All types of batch or continuous crystallizers. Facilities available for pilot testing of samples. Chicago Bridge & Iron Co.

104L Screw Pumps. Capacities from 1 to 1,000 gal./min.; viscosities from 32 SSU to 1,000,000 SSU. Details from Sier-Bath Gear & Pump Co.

105A Chemical and Petrochemical Plants. The Lummus Co. has more than fifty years' experience in design and construction.

106L Wire Cloth Catalog. Ninety-page catalog from Cambridge Wire Cloth Co. describes full range of wire cloth available.

107A Pre-engineered Heat Exchangers. Bulletin with complete technical information, unit diagrams, pressure tables, specification data. Whitlock Manufacturing Co.

108L Liquid Gas Pumps. Specially designed for handling liquid oxygen, nitrogen, and other gases. Bulletin from Lawrence Pumps, Inc.

109A Tubular Filters. Easy maintenance and low cost in small or variable processes. Industrial Filter & Pump Manufacturing Co. Bulletin.

110L Spray Nozzle Catalog. Complete selection of standard nozzles available from stock. Spray Engineering Co.

111A Plant Layout Kit. Problems in process and chemical plant layout simplified by "Visual" planning cube. Brochure with complete details. "Visual" Plant Layouts, Inc.

112L Anti-Corrosive Wire Cloth. Complete line of woven wire cloth and wire cloth parts in all malleable metals. Catalog from Newark Wire Cloth Co.

113A Leakproof Pumps. The "Chempump" combines pump and motor in single leakproof unit. No shaft sealing device required. Details from Chempump Corp.

114L Rota-Cone Vacuum Dryer. In sizes from 0.1 to 325 cu.ft. operating capacity. Folder with specifications from Paul O. Abbe, Inc.

115A Heat Transfer Equipment. In all grades of carbon, alloy, and stainless steels, nickel, aluminum, and special low-temperature materials. General catalog from Efco Heat Transfer Equipment.

116L Insulated Thermocouple Wire. Bulletin from Claud S. Gordon Co. describes advantages of bonded staple yarn insulation and gives ordering information.

116R Water Demineralization Cost Information. Reprint of article outlining costs by various ion-exchange systems. Illinois Water Treatment Co.

117A Direct Flow Pumps. Condensed catalog on complete line of pumps made by Aldrich Pump Co.

118L Impervious Graphite Heat Exchangers. Over 125 increments of heat transfer surface available in standard "Impervite" tube and shell exchangers. Bulletin from Falls Industries, Inc.

119A Diaphragm Valves. Wide choice of body and diaphragm materials. Crane Co.

121A Pump Bulletin. Describes Type DL-DM interchangeable-component pump line. Specifications, dimensional data, performance charts. Peerless Pump Division, Food Machinery and Chemical Corp.

122TL Germanium-Selenium Rectifiers. Priced to compete with ordinary mass-produced equipment. Details from Sel-Rex Corp.

122BL Adjustable Sprocket Rim. Simplifies pipe layout, fits any size valve wheel. Descriptive catalog and price list. Babbitt Steam Specialty Co.

123A Heat Transfer Medium. Complete technical data on Dowtherm available from the Dow Chemical Co.

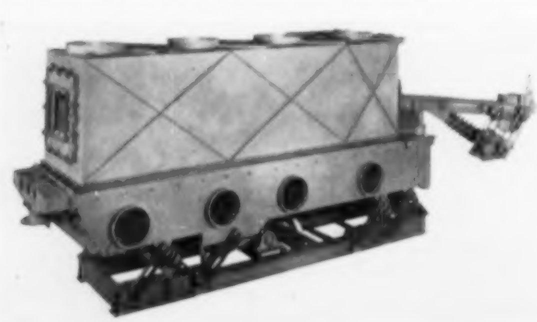
124L Standardized Heat Exchangers. Quick delivery on all types of stainless steel heat exchangers. Doyle & Roth Manufacturing Co.

125A Equipment Fabrication. Chemical processing equipment in steels and alloys. 100 years of experience. Graver Tank & Manufacturing Co.

126L Centrifugally Cast Pipe. Alloyed to resist corrosion and high temperature. Wide range of sizes. Duraloy Co.

(Continued on page 84)

DEVELOPMENTS OF THE MONTH (Cont.)



396 Low-Cost Vibrating Dryer. Carrier Conveyor Corp. offers a new low-cost mechanical dryer especially suitable for pharmaceutical and chemical powders. Illustrated is 3 ft. by 15 ft. model, fed by small Carrier feeder. Combination handles 900 pounds per hour of 100-mesh white crystalline material, drying it from 10% to ¼% moisture without harming the crystals. Conveying speed is variable from 4 to 6 feet per minute, with an average retention period of 2½ minutes. Steam coils preheat the drying air which is forced through the screen and the vibrated mat of material. Approximately 3,000 cubic feet per minute of drying air is used, zoned by internal baffles so that inlet temperature at discharge end is 150° F. Maximum temperature at wet end is 200° F. A vibrating hood or plenum chamber is provided to reduce air velocity and consequent dust losses. Full details available from the manufacturer. Circle number 396 on Data Post Card.

(Continued on page 84)

PRODUCTS ADVERTISED IN THIS ISSUE (*Cont.*)

127A Conveying Equipment. Bulletins from Stephens-Adamson Mfg. Co. describe many types of bulk handling equipment for the chemical industry.

128L Pulse Code Telemetering. Bulletin gives full details of "Varec" pulse code telemetering systems. Vapor Recovery Systems Co.

129A Horizontal Plate Filters. Efficiency and dependability with any type of filter aid. Sparkler Manufacturing Co.

131A Stainless Steel-Enclosed Flowmeters. Catalog from Fischer & Porter Co. describes 1700 Series Flowrators.

132L Filtration Catalog. Complete with specifications for planning new filtration facilities. D. R. Sperry & Co.

132R Process Equipment. Including custom design and foundry service. Consulting services available. Goslin-Birmingham Manufacturing Co.

133A Polyethylene Tower Packing. Folder on "Tellerette" explains increased efficiency and capacity, lighter weight, unbreakable units, tray column characteristics. Harshaw Chemical Co.

134TL Processed Fullers Earth. Available in standard meshes from 2/4 to 200 up. Floridin Co.

134BL Automatic Weighing Units. From single weighing units to fully programmed installations. Glengarry Processes, Inc.

135R Water Stills and Demineralizers. Catalog with details of extensive line of pure water equipment. Barnstead Still & Demineralizer Co.

136L Filtration Fact and Data Book. Many difficult filtration problems solved by use of Shriver filter presses. T. Shriver & Co.

137L Compressor Catalog. From single stage to six stages, from 125 to 25,000 lb./sq.in. Norwalk Co., Inc.

137R Water Collection Systems. Informative booklet from Ranney Method Water Supplies, Inc.

138L Fused Silica Lab Wire. Bulletin from Thermal American Fused Quartz Co.

138TR Batch Mixers. 100 lb. to 8,000 lb. per batch. Literature from H. C. Davis Sons' Mill Machinery Co.

139TR Equipment Design and Fabrication. Artisan Metal Products, Inc. specializes in design for special processing problems.

139BR Centrifugal Pump Catalog. Horizontal and vertical shaft types in complete range of sizes. Nagle Pumps, Inc.

140BL Constant-Flow Cooling Unit. Multiadjustable, constant-flow system automatically maintains temperature to plus or minus 0.5° C. Ace Glass, Inc.

141A Heat Exchange Equipment. Bulletins from Pfaudler Co. describe heat exchange equipment, towers, pumps, etc.

142BL Project Engineering Textbook. Covers all phases of planning, organizing, and executing projects. John Wiley & Sons, Inc.

142BR Bin Level Indicator. Literature from the Bin-Dicator Co. describes new motor-driven paddle type bin level indicator.

143TR Dryers and Coolers. Technical data and information on dryers, coolers, ammoniators, granulators, elevators, conveyors for the chemical industry. Edw. Renneburg & Sons Co.

143BR Fused Quartz-Fused Silica Data File. Standard apparatus, crucibles, trays, etc. available for prompt delivery. Amersil Co.

144TL Mechanical Sealing Book. Reference book for maintenance engineers and equipment designers. Durametallic Corp.

144BL Skin Irritant Protection. "Kerodex" said to be effective against many industrial skin irritants. Ayerst Laboratories.

145R Equipment Design and Fabrication. Heat exchangers, containers, pressure vessels, steel and alloy plate fabrication. Downingtown Iron Works, Inc.

146TL Laboratory Glassware. Price list from Doerr Glass Co.

146BL Spray Nozzle Catalog. Complete technical data from Spraying Systems Co.

147R Mix-Mullers. Simpson Mix-Muller combines advantages of batch mixing with adaptability to continuous processing. Details from Simpson Mix-Muller Division, National Engineering Co.

150BL Heat Exchange & Process Equipment. General bulletin from Manning & Lewis Engineering Co.

151L Jobs in Propellants. Physical chemists, metallurgists, chemical engineers, physicists, chemists wanted by Jet Propulsion Laboratory, Calif. Institute of Technology.

151R Centrifugal Pump Bulletin. Enclosed impeller and open impeller types. Frederick Iron and Steel, Inc.

152TL Chlorinators. Bulletin from Wallace & Tiernan, Inc. describes features of W&T V-notch Chlorinators.

152BL Chlorine Detector. Detects as little as 3 p.p.m. in continuous air-stream sample. Literature from Wallace & Tiernan, Inc.

153L Direct-Acting Flow Rate Regulators. Technical bulletin from W. A. Kates Co.

153R Internally-Geared Motor. U. S. Syncrogear "packaged" assembly includes high-speed motor and enclosed gear-train in single case. Booklet from U. S. Electrical Motors, Inc.

154L Polyethylene Atmosphere Scrubbers. Detailed literature featuring ventilating and exhaust systems. American Agile Corp.

154BR Dust Determination Equipment. Five different models employing continuous oscillating or gravimetric methods. Joseph B. Ficklen.

155TL Laboratory Filters. In sizes for all laboratory requirements. Cylinder type. Ertel Engineering Corp.

155TR Precision Bore Tubing. In Pyrex, Vycor, and most electronic glasses. Detailed catalog. Wilmad Glass Co.

155B Welded Chemical Vessels. Complete facilities for fabrication in carbon or stainless steel, aluminum, or special alloys. R. D. Cole Manufacturing Co. Literature.

162BR Vacuum Equipment. Steam jet ejectors, condensers, vacuum equipment. Jet-Vac Corp.

163BL Indicating Pyrometers. 21 ranges for temperatures from minus 400 to plus 3,000° F. Accuracy 2% of full scale. 40-page catalog from Assembly Products, Inc.

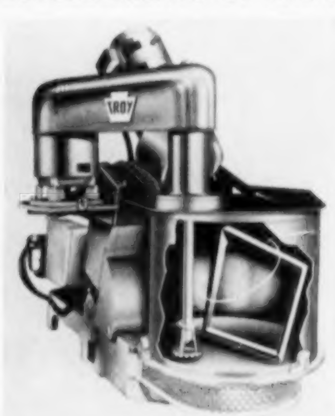
163BM Panel Heating Coils. Dean Thermo-Panel coils replace inside heating coils in many process applications. Bulletins from Dean Thermo-Panel Coil Division, Dean Products, Inc.

163R Silicone Defoamer. Dow Corning Corp. will send free sample of Antifoam B.

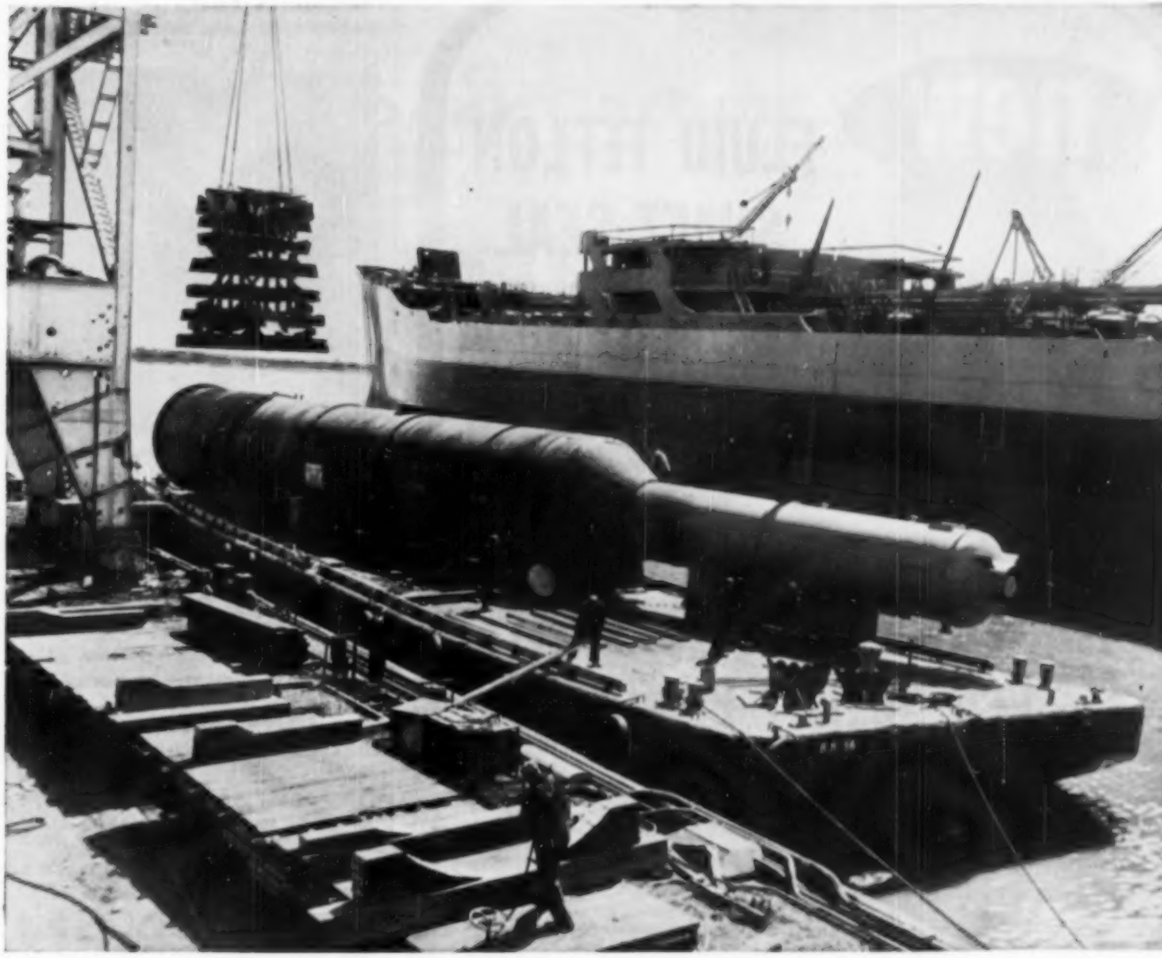
IBC Controlled Volume Pumps. Capacities to 1,350 gal./hr./liquid end. Milton Roy Co.

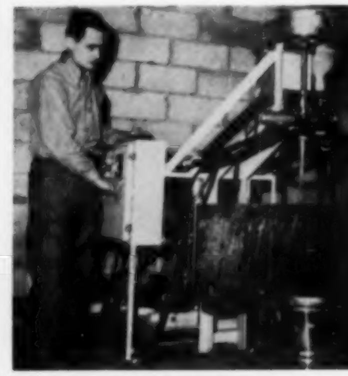
OBC Industrial Mixers. Bulletins from Mixing Equipment Co. give latest mixing information and full description of Lightnin Mixers.

DEVELOPMENTS OF THE MONTH (*Cont.*)



397 Duplex Mixer-Disperser. Combines mixing advantages of a rugged, diamond-shaped agitator, rotating on its angular axis, with the mulling, shearing, and impinging action of a powerful revolving disperser head. Turning at 3,600 rev./min., the disperser head forces the material into the mulling zone and out toward the sides of the rotating change can, where it is again swept into the agitator blade. The intense hydraulic shear developed insures excellent wetting action, improved color dispersion, and uniform blending into a smooth, finished, homogeneous batch. Unit is at present available in 60-gallon size. For further information, circle number 397 on Data Post Card.





The new plant of Nopco Chemical Co. is the first in the East to be devoted solely to research and production of urethane plastic foams. It represents Nopco's first major step in its expansion into the plastics field. The machine pictured is a new one that makes it possible to use assembly-line techniques to produce pour-in-place urethane foams.

Commercial scale production of a polyolefin catalyst will be started this year by Davison Chemical Co. division of W. R. Grace under license from Phillips Petroleum. The new Davison plant will be located at Cincinnati adjacent to the company's large petroleum cracking catalyst plant at that location. Rated initially at 8,000 pounds a day, the catalyst is chromia on silica-alumina and Davison's know-how with silica-alumina gels will be valuable. □

Tentative plans for a merger between The Chemical and Industrial Corp. of Cincinnati and the Clopay Corp. have been dropped and negotiations definitely terminated. Chemical and Industrial will continue its normal business of designing and constructing plants for the production of nitric acid, phosphoric acid, sulfuric acid, and the further processing of anhydrous ammonia. No changes are contemplated in the business of the company. □

Commercial Solvents Corp. has voted a merger of Thermatomic Carbon Co. into Commercial Solvents. Basis is 18 shares of Commercial Solvents stock for each share of Thermatomic Carbon. □

The boards of directors of Carrier Corp. and Elliott Co. have agreed on a basis whereby Elliott will be merged into Carrier. □

Vinyl paint production in the U. S. should more than triple in the next four years, according to James Dillon of National Starch Products. □

News from
National Carbon Company

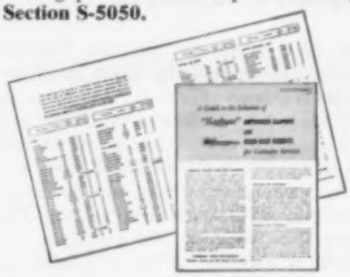
Division of Union Carbide Corporation • 30 East 42nd Street, New York 17, N. Y.

Sales Offices: Atlanta, Chicago, Dallas, Kansas City, Los Angeles, New York, Pittsburgh, San Francisco. IN CANADA: Union Carbide Canada Limited, Toronto

PROCESS EQUIPMENT BRIEFS

Extensive Corrosion Resistance Table on "KARBATE" Impervious Graphite Now Available

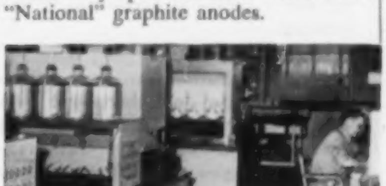
A new guide to selection and use of "Karbate" impervious graphite and "National" resin base cements in over 100 corrosive applications. 4-page booklet contains specific grade recommendations and information on field testing procedures. Request **Catalog Section S-5050.**



National Carbon Expands Carbon and Graphite Development Program

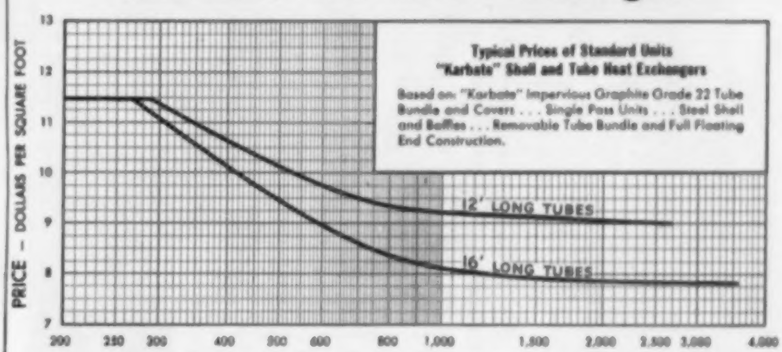
NIAGARA FALLS DEVELOPMENT LABORATORY

Maintaining its leadership in the broadening industrial use of carbon and graphite, National Carbon has expanded product development facilities at Niagara Falls, New York, to supplement new major research activities at Parma, Ohio. A large share of the expansion is devoted to development and evaluation of graphite anode materials for the electrolytic production of chlorine-caustic, chlorates, sodium and magnesium. The test room shown below contains miniature electrolytic diaphragm-type chlorine cells used in laboratory performance tests on "National" graphite anodes.

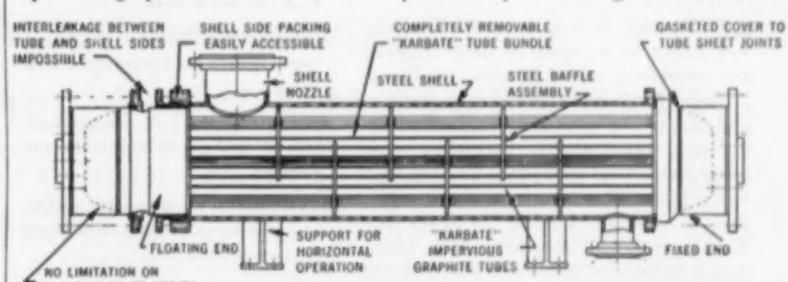


ELECTROLYTIC ANODE TEST ROOM

Quick Reference Chart Covers Prices of "KARBATE" Impervious Graphite Shell and Tube Heat Exchangers

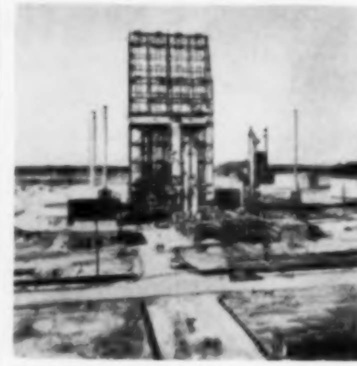


New pricing charts on "Karbate" impervious graphite heat exchangers show their economy for all types of heat transfer involving corrosive fluids. Standard units assembled from stocked components, covering 16 shell sizes from 6" through 45" diameter and containing from 9 to 685 ⅞" I.D. impervious graphite tubes in 6, 9, 12, 14 and 16 ft. tube lengths, can be shipped in 3 to 5 weeks. Cut away view below demonstrates how sturdy, durable construction utilizes "Karbate" impervious graphite's corrosion resistance, immunity to thermal shock and freedom from metallic contamination in corrosive service. For price and product data, request **Catalog Section S-6800.**



View at right shows assembly and test facilities producing "Karbate" shell and tube heat exchangers. Units have "Karbate" impervious graphite tube bundles and covers assembled in shells of steel or materials such as glass or rubber lined steel, "Haveg" phenolic resin, aluminum or impervious graphite.

NATIONAL
TRADE-MARK



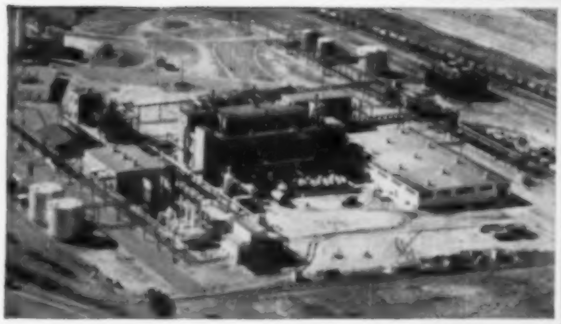
This delayed coking unit, one of the largest ever designed, handles the heaviest feed ever charged to a delayed coker. In operation at the Yorktown, Va., refinery of American Oil Co., the 4 coke drum unit produces light and heavy gasoline, light and heavy gas oils, and 600 tons of coke a day. It was designed and engineered by The Lummus Co.

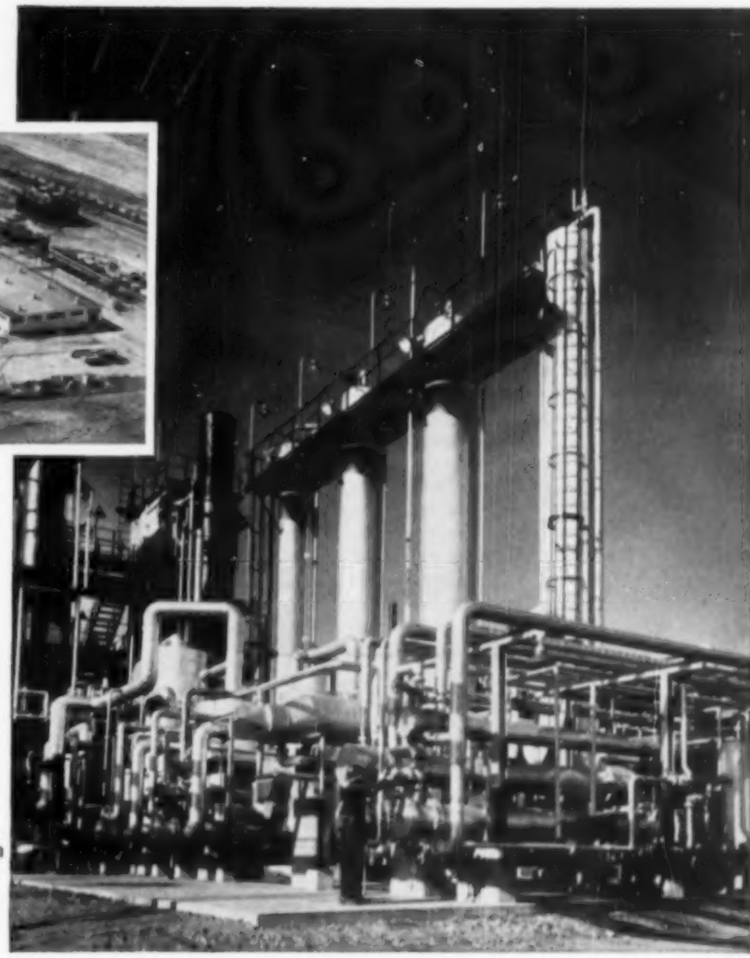
A new plant to produce barium monohydrate will be built by Sherwin-Williams Co. A new process developed by Sherwin-Williams will be used for the production of barium hydrate direct from barytes ore. The new method will give a barium monohydrate of at least 99% purity. The new unit will cost over a million dollars, is expected to be in production in early 1958. □

A multi-million-dollar refinery with a capacity of 20,000 bbl. a day will be built at Port Moody, B. C. (near Vancouver) by British American Oil Co. The completely integrated plant is scheduled for completion late in 1958. Contract for building the refinery has been awarded to Canadian Kellogg Company, Ltd. □

The John Jay Hopkins Laboratory for Pure and Applied Science of General Dynamics Corp.'s General Atomic Division is now under construction at San Diego, Cal. The construction now underway is on the first of four buildings, the experimental building, to cost $1,248,000 and be built by Haas-Haynie-Frandsen, Inc. The three buildings still to be contracted for will be a science building, an engineering and office building, and a library and technical service building. □

An ore preparation plant for processing manganese and chromium ores will be built by Union Carbide at Warwick, Va. The plant will grade and classify about 30,000 tons of ore a month. □





the future in

DRUGS AND BIOCHEMICALS

Allan J. Greene | Chas. Pfizer & Co., Inc., Brooklyn, N. Y.

The miracle drug of yesterday is commonplace or even obsolete today. But a new one rises periodically to take its place and is the talk of the industry, the medical profession, and the Sunday supplements.

Because of this rapid and spectacular emergence of new products, obsolescence in the pharmaceutical industry is rapid. Since one such new product can drastically alter the financial outlook for any single company, research competition is keen. Of course, all these developments work to the health benefit of all, but it is exceedingly difficult to see where the next break-through may occur and thus it is even more difficult to predict its effect. A further complication is the fact that, since research is so competitive in this industry, the programs are closely guarded secrets.

But basically the picture is optimistic, not only economically, but in research. The future will bring new sales records, new products, new processes, new opportunities, and new benefits for us all. This optimism is prevalent in the pharmaceutical industry and is reflected by ever-increasing capital expansion programs.

Top in Growth

According to the *Advance Report of the Census of Manufactures*, the value of pharmaceutical preparations shipped by all producers in the United States increased 250% between 1947 and 1956. This places the pharmaceutical industry at the top as regards growth.

This past record leads the industry to look forward optimistically to the next ten years of growth. A statistician could apply a "trend line" to these figures and predict that in 1965 pharmaceutical sales will approach $4 billion, all other things being equal. Of course, all other things will not be equal, but it is somewhat difficult to predict whether conditions will be better, worse, or equivalent. Nevertheless, there are no finite signs of a leveling off in this area of the American industrial scene. In fact, in the biochemical end of the business, new products are appearing so fast that for the first time in years there is a slight squeeze on production facilities. Although this can be exasperating from the point of view of the eager sales manager, it does have compensating advantages from the general industry standpoint. One such advantage is the rectification of the cost-price squeeze through the law of supply and demand (unless the Government repeals that law). An example is the recent increase in the price of penicillin. This was most unusual, since this product had one of the longest decline records in the entire chemical industry.

Export

Foreign development alone gives cause for optimism in the industry. Evidence is already available of the increasing importance of foreign markets to American pharmaceutical concerns and industry in general. Pfizer products, for example, are now distributed directly in 57 major foreign markets, and sales in these areas make up a good percentage of the company's total. The growing nationalism of many of these countries has brought about a change in the mode of operation of American concerns within them, but has not seriously affected the potential that is there. A company can no longer merely export, but must carry out full scale operations within many of the countries if it wishes to market its product there. This naturally presents problems, but the challenge is being met.

Forefront of Research Effort

Another reason for optimism concerning the future of the industry is—research.

The pharmaceutical industry is in the forefront of research effort, dedicating 4 to 5% of each sales dollar to research. (In some cases, companies dedicate as much as 7%.) This is somewhat higher than the chemical industry average.

The industry is proud of its past accomplishments, such as antibiotics, corticosteroids, mental drugs, etc., but it has far from exhausted the concepts which were new only 15 years ago. In antibiotics new and more powerful agents are still being uncovered and will continue to be uncovered. The viral diseases are now under attack and they will yield to science. The Salk polio vaccine is only the start. Vaccines for the common cold, respiratory infections, and measles may be "just around the corner."

Preventive Medicine

The vaccines all fit in with the coming theme of preventive medicine, wherein more and more emphasis will be placed on the prevention rather than the cure of disease. This could bring about radical changes in the industry, but these changes need not be destructive; perhaps quite the opposite. Preventive medicine would make every individual a potential customer, the healthy as well as the sick.

Probably before preventive medicine is a complete practical reality, the concept of maximum health will be established and practiced. According to this theory, the body is in a state of equilibrium, and disease is a distortion of this equilibrium in any one of many ways, some of which have previously not been manifest. The treatment of disease will involve more than elimination of the causative organism. The whole patient will be treated and many weapons brought to bear in order to return his body to the equilibrium state as soon as possible. This will focus more attention on hormones, vitamins, enzymes, the endocrine system, and the entire complex chemistry of the body.

To return to the more foreseeable future, there is at present tremendous activity in the cancer field. The program is attracting Government, academic and industrial attention. Chemotherapeutic agents may well be on the way. A limited amount of success has already been had with a handful of chemicals in the treatment of cancer. More are coming. Dramatic results of this entire program may be available within the next five years.

Arteriosclerosis, another major killer of the elderly adult, may also soon succumb to the advance of science. There is some healthy controversy now as to the etiology of this disease, but this adds a little spice to the search for new knowledge in the area. Cardiovascular diseases are being attacked on prophylactic as well as therapeutic lines, and the industry has every reason to hope for success.

New steroidal compounds for use against arthritis are even now on the scene. Delta-1-hydrocortisone followed hydrocortisone. But pharmaceutical companies do not consider this the end and there will be newer and better agents for the treatment of this dread crippler. The development of processes for making these compounds available at lower costs has led to the indus-

(*Continued on page* 92)

YOU SAVE WHEN YOU SPECIFY

B&W ERW Tubing For Heat Transfer Equipment

When you specify B&W Electric-Resistance-Welded Carbon Steel Tubing in your heat transfer equipment, you not only have lower original cost—you are assured of savings where they count—in operating costs. Its uniform wall thickness provides high heat transfer efficiency. And dimensional accuracy from tube to tube assures easier fitting into tube sheets with less time required for rolling-in operations.

Used in oil preheaters and heat exchangers at major refineries, B&W ERW Tubing is made to ASTM and ASME specifications. It must pass rigid inspection and testing standards in manufacture. Its value has been proved in such heat transfer applications as boilers, condensers, preheaters, economizers, evaporators, and refrigeration equipment.

A call to Mr. Tubes, your nearby B&W Tube representative, will bring you economical recommendations plus quick deliveries. Write for Bulletin 412. The Babcock & Wilcox Company, Tubular Products Division, Beaver Falls, Pa.

B&W TUBULAR PRODUCTS DIVISION

TA-7008-PP2

Seamless and welded tubular products, seamless welding fittings and forged steel flanges—in carbon, alloy and stainless steels.

DRUG FUTURES

(*Continued from page 90*)

trial application of synthesis of combined microbiological and chemical techniques. (Personally, I feel that the future will see an even greater integration of microbiology and chemistry.)

Mental Disease

Further advances can also be expected in the field of mental disease. Activity has been stimulated by the advent of the mental drugs and tranquillizers. The effectiveness of these new drugs, together with other experimental results, is lending more and more support to the theory that mental disease and psychotic states may be caused by metabolic disturbances. This could be as exciting a discovery as the finding that infectious diseases are caused by microorganisms, and would open whole new fields for chemotherapy.

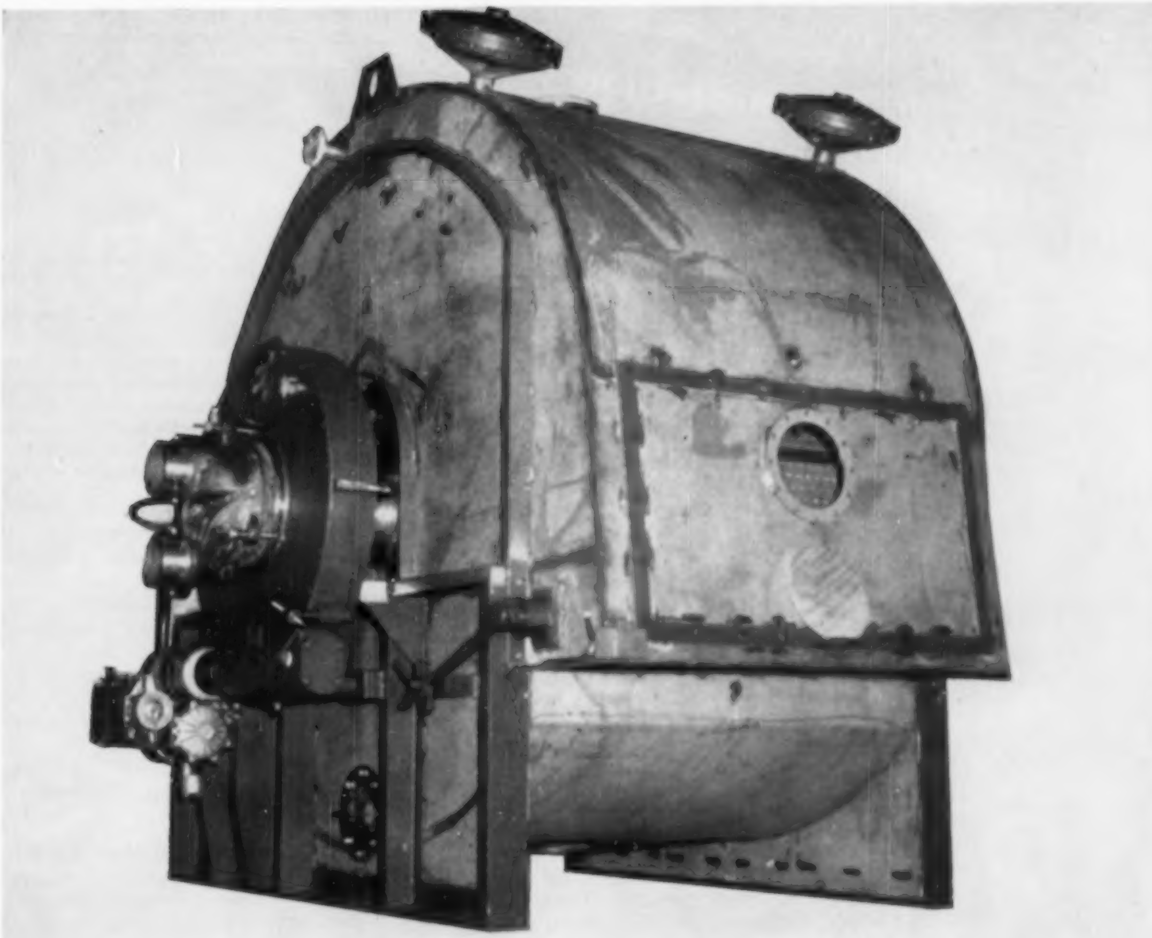
Speculation could go on and on about what lies on the other side of the horizon. However, it is hoped that what has been said is sufficient to give an idea of why the drug and biochemical industry is looking forward to 1965 with confidence.

Condensed from a paper delivered at A.I.Ch.E. meeting, White Sulphur Springs, West Virginia.

Union Carbide Corporation is the new name of Union Carbide and Carbon. Carbide and Carbon Chemicals is now Union Carbide Chemicals Co.; Linde Air Products Company division is now Linde Company. The other divisions of Union Carbide retain their present names. □

Di-isobutylene facilities have been completed at the Texas Co.'s Port Arthur, Tex., refinery. Initial capacity will be 8 million pounds annually but provision is being made for expansion. □

Construction of a silicon oxide pigment plant is in the works at Tuscola, Ill., for Cabot Carbon Co., a subsidiary of Godfrey L. Cabot of Boston. Basic production process is the vapor phase hydrolysis of silicon tetrachloride in a hot gaseous environment. Basic raw materials are silicon carbide, chlorine and hydrogen. Hydrogen will come from the nearby U. S. Industrial Chemical's plant, and the by-product HCl will be sold to National Petro-Chemical Corp., also nearby. □



EIMCO FILTERS . . . CUSTOM-BUILT to FIT the JOB

Shown above is another Eimco custom built filter . . . quality designed for continuous vacuum operation to fit the specific needs of a chemical processing firm.

Solution to this customer's filtration problem began at The Eimco Research and Development Center.

Through highly practical pilot plant tests, Eimco defined control factors, measured the effects of varying conditions and was able to present accurate conclusions to this firm's engineering staff. The result: A filter designed and built to efficiently handle the required job.

Eimco can guarantee duplication of pilot plant results in commercial size filter stations because new filtration methods and designs provide a wide selection of "tools" to handle tough slurries efficiently and economically. Some of these Eimco designs are: Hy-Flow anti-friction valves and piping . . . enclosed vapor tight hoods . . . air actuated diaphragms for control of compression rolls . . . and Snap Blow discharge.

Eimco knows that variables in filtration (however slight they may seem) are too numerous to get effective coverage from "production-line" manufacturing. We are convinced that successful operation in any flow sheet depends on careful analysis by Eimco specialists and equipment individually constructed on basis on their conclusions.

We solicit an opportunity to show you the benefits of this dependable engineering service.

THE EIMCO CORPORATION

SALT LAKE CITY, UTAH

Research and Development Division, Palatine, Illinois • Process Engineers Inc. Division, San Mateo, California
Export Offices: Eimco Building, 51-52 South Street, New York 5, N. Y.
BRANCHES AND DEALERS IN PRINCIPAL CITIES THROUGHOUT THE WORLD

B-259

This salt spray test cabinet is in the new laboratory built by Raybestos-Manhattan for developing and testing adhesives, coatings, and sealers made by the company. The new lab is indication of the growing importance to the company of its new line, in production now for less than a year.

The first pulp mill to be constructed in Canada's resource-rich province of Alberta has gone on-stream. A bleached sulfate mill owned by North Western Pulp & Power Limited, it represents a $42 million investment. North Western is jointly owned by St. Regis Paper and North Canadian Oils Limited. St. Regis directed the design and construction of the mill and manages its operation. Rated capacity of the mill is 430 tons of bleached kraft pulp per day. □

Large new zirconium plant has just been opened by the Wah Chang Corp. at Albany, Oregon. Both reactor and commercial grade zirconium will be produced. □

The Girdler Co. will design and build a sulfur recovery plant at Linden, N. J., for General Chemical Division of Allied. General Chemical will use hydrogen sulfide from Esso Standard's Bayway, N. J., refinery to produce about 60 tons a day of elemental sulfur. At the Girdler plant a mass spectrometer will be used to analyze plant tail gases to minimize escape of sulfur into the atmosphere. Completion is scheduled for late this year. □

These fractionating units for the low temperature separation of gases are the largest ever built in Canada. Built by L'Air Liquide, Canadian engineering and construction affiliate of American Air Liquide, they are part of a 300 ton a day Oxyton (tonnage oxygen) plant recently completed and shipped from Montreal to a large chemical company in the U. S.

Fresh Perspective...

Perspective view of the raising of two of four 200 foot columns at Cosden Petroleum Corporation's new Ultra-fractionation and styrene manufacturing plant (Big Spring, Texas). Designed and built by Badger, this plant uses a daring new processing concept to make styrene directly from gasoline! Brochure available on request.

The ability to put engineering problems in a *fresh perspective* — to subject them to a point of view that leads to new solutions — is at the root of Badger accomplishments like these:

... a commercially practical method of separating ethylbenzene from gasoline by Ultra-fractionation.

... a continuous process for producing sodium-hydrogen compounds.

... the successful application of a new process for deriving high quality light oils from coal — without acid treating.

An intangible that has been called "The Precious Plus behind a Badger blueprint," this refreshing ability to apply *new* thinking to difficult engineering problems has produced two important results:

1. Top petroleum and chemical processors are securing better processes, more economical plants.

2. Badger has become one of the world's fastest growing contract engineering firms.

Whether your project is commonplace or complex, calling in Badger is the first step toward securing the precious advantages that can come only from taking a *fresh perspective*.

Badger's Key Man Operating Policy: "The Badger man who submits your proposal is always a Badger principal — always the Key Man responsible for the execution of your job."

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NUCLEAR NEWS

W. R. GRACE TO BUILD REACTOR FUEL RAW MATERIAL PLANT

A new uranium, thorium, and rare earths alloys plant, described as the first of its kind financed and operated entirely by private enterprise, will be built at Erwin, Tenn., by W. R. Grace & Co.

Construction is underway on W. R. Grace's new plant to produce basic raw materials for nuclear reactor fuel. The uranium, thorium, and rare earths alloys will go to present reactors and those under construction, both for private users and defense units.

The installation will consist of a solvent extraction plant producing pure thorium and uranium salt, a reduction plant which will convert the salt to metal powder or sponge, and a melting and casting plant containing both vacuum induction and arc melting facilities. The plant will be made available as a "job shop" to serve the needs of designers and builders of atomic power reactors. It will not make finished fuel elements but will concentrate on making the basic thorium and uranium metals, alloys, or oxides for fuel element fabricators.

J. P. Grace, president of the company, said, "We are very hopeful that this plant will serve as a nucleus around which the steadily widening number of companies interested in the atomic energy power field will help us build a free-enterprise center for atomic fuels advanced research and for a pilot-plant-stage development laboratory."

H. K. Ferguson Co., Cleveland, O., has been selected as architect-engineer for the design of the Experimental Breeder Reactor II, part of AEC's five-year program for the development of competitive electric power from nuclear energy. The sodium-cooled EBR-II will be built at the National Reactor Testing Station, will be designed to produce 62,500 kilowatts of heat, 20,000 kilowatts of electricity. □

A contract to study the feasibility of building a gas-cooled nuclear propulsion system for an oil tanker has been awarded by AEC to the General Atomic Division of General Dynamics Corporation in San Diego. The study will include, in addition to the nuclear and engineering aspects, the economy, efficiency, and safety aspects of such an operation. □

NUCLEAR NEWS

The ARGONAUT, Argonne National Laboratory's assembly for university training, is a new educational reactor recently launched by the Laboratory. Costing less than $100,000, the new reactor assembly will enable students to observe the behavior of the reactor as fuel is added to make it critical. The reactor will give nuclear engineering and science students the much-needed opportunity to study operation, chemical analysis, radiations, etc., first hand.

The site for the U. S. Army Ionizing Radiation Center will be the Sharpe General Depot at Stockton, Calif. The Army Corps of Engineers will build the experimental center which will include a nuclear reactor built by AEC.

The center is planned for investigating the use of ionizing radiation for the preservation of food, and for other projects of the Department of Defense. □

Proposed new reactor to be built and operated by Westinghouse Electric will be cooled and moderated by ordinary water under pressure, will use U-235 enriched uranium as fuel. To be known as the Westinghouse Testing Reactor, the facility will generate heat equivalent to 20,000 kilowatts. It will be used for developing and testing power reactor fuel elements, for radiation damage testing of materials and components, and for limited production of radioisotopes. Westinghouse plans to make the facility available to others on a commercial basis. □

A contract to install the reactor portion and related systems and conduct construction work in connection with the Organic Moderated Reactor Experiment has been awarded to Fluor Maintenance, Inc., a subsidiary of Fluor Corp., by Atomics International Division of North American Aviation which is building and installing OMRE for the AEC. □

NUCLEAR NEWS

AEC has accepted, as a basis of contract negotiations, a proposal by Babcock and Wilcox Co. to design, construct and test operate a nuclear propulsion plant for a nuclear powered merchant ship. The award of a contract will depend on the successful completion of the authorized negotiations.

Under the proposed contract, the B&W reactor will be a 20,000 shaft horsepower pressurized water reactor system of advanced design. The project is to be completed in 39 months. The pressurized water reactor system was chosen because it offers the best prospect for achieving desired technological advances in a relatively short time. The reactor for this first nuclear powered ship will be unclassified, the new technology developed will be available to American industry. □

A closed circuit television camera is being groomed by General Electric engineers for the difficult task of patrolling the rear face of an atomic reactor at the Hanford atomic plant. Designed to move automatically along a monorail near the wall of the reactor, the camera is protected against radiation and will transmit a picture of reactor components to an operator seated at a console behind thick radiation shielding. □

Operation of A.E.C.'s heavy water plant near Dana, Ind., will be discontinued and the facility placed in a standby condition. The Commission's other heavy water plant, at Savannah River, will continue to operate, since forecasts of future heavy water requirements now indicate that only one of the heavy water production units will be needed during the next few years. The Dana plant was selected for shutdown because the cost of producing heavy water is lower at Savannah River, and the Savannah River plant's equipment has greater corrosion resistance. □

The Experimental Boiling Water Reactor (EBWR), located at the Atomic Energy Commission's Argonne National Laboratory, Lemont, Ill., has generated electric power at its full design rating of 5,000 kilowatts for the first time. It is the first of the five reactor projects initiated in 1954 under the Commission's civilian power reactor development program to actually generate electricity. The unique feature of the EBWR is that live steam is actually generated in the uranium core by nuclear heat and is piped directly to a turbine. □

KNOW YOUR AUTHORS AT SEATTLE . . .

- **Seattle Technical Program offers practical, "how to" information to take back home, use as basis for future decisions.**
- **Here's aid in planning your trip to and from Seattle—center of booming Northwest chemical industry, on periphery of America's great West—which every chemical engineer must see to appreciate properly.**

Marshall T. Ramstad

Pennsylvania Salt Mfg. Co. of Washington
Tacoma, Washington

When A.I.Ch.E. holds its National Meeting in Seattle June 9-12, it will mark the first time the chemical engineers have met in the Puget Sound area. Perhaps nothing could better underline the growth of the area into a major center of the chemical industry.

Location of the meeting being in Seattle—on colorful Puget Sound and within sight of Mt. Rainier—Sunday has been left open (until 5 P.M.—when the cocktail "get acquainted" party begins) so that you and the family can enjoy some of the sights. Be sure to take in Olympia National Rain Forest, or Mt. Rainier on your way in to the headquarters hotel.

For a combination of recreation with fellowship, Tuesday afternoon will have only one technical session, and that one will be short (two papers), so that everyone can go on the major planned outing of the meeting—the Salmon Bake. You'll get aboard a specially chartered boat at 3:30 in the afternoon and cruise across magnificent Puget Sound to Kiana Lodge where a salmon bake in all the rich tradition of the Northwest will be held in honor of the visiting chemical engineers. There will be dancing and swimming on the trip, and the return moonlight sail across the Sound on a June night should provide unforgettable memories. Be sure to make your plans early and sign up at the time of registration for the meeting, as the attendance may conceivably exceed the "best laid plans."

FOR YOUR WALLET

A.I.Ch.E. National Meeting, Seattle, Washington, The Olympic Hotel, June 9-12, 1957.

Registration: begins Sunday, June 9, 10 A.M., Spanish Lounge.

First Technical Session: 9 A.M. Monday.

Last Technical Session: 4 P.M. Wednesday.

Special Note: Salmon Bake 3:30 P.M. Tuesday.

OFFICIALS YOU'LL GET TO KNOW

Bob Florine, chmn. of the Entertainment Comm. (far right) outlines the activities lined up for the meeting to (l. to r.) J. T. Stephan, chmn. of Hotel and Meeting Rooms Comm.; J. G. Knudsen, Technical Program chmn.; C. E. Kent, vice chmn., Comm. on Arrangements; M. M. David, treas. of Comm. on Arrangements; at one of the all-day sessions of the hardworking committee. Other committee members are: W. S. Munro, chmn., Arrangements; J. B. Heitman, sec'y., Arrangements; A. L. Babb, chmn., Registration; H. E. Hanthorn, chmn., Program Copy; M. T. Ramstad, chmn., Publicity; B. B. Butler, chmn., Plant Visits; E. T. Merrill, chmn., Printing; and Mrs. H. K. Benson and N. Robertson, Ladies Comm.

acquaint yourself with
THE RESOURCE-RICH WEST

Highlights to Take Home

Here is a brief summary of what you will take home from the technical program:

Spray Drying—a new type of dryer, with a report on effect of drying conditions on properties of particles.

Novel Instrument—measures humidity and temperature in a hot, turbulent stream.

Plant Sites—Effect of natural gas and power on Pacific Northwest's attractiveness as the place to locate your plants.

Chlorine and Caustic—the latest on new types of mercury cells. Plant operating and maintenance data on mechanical rectifiers.

Electrodeposition—from nonaqueous solvents, from fused salts.

Pulp Manufacture—continuous pulping, corrosion resolved by stainless steel, evaporator technology, dimethyl sulfide from black liquor.

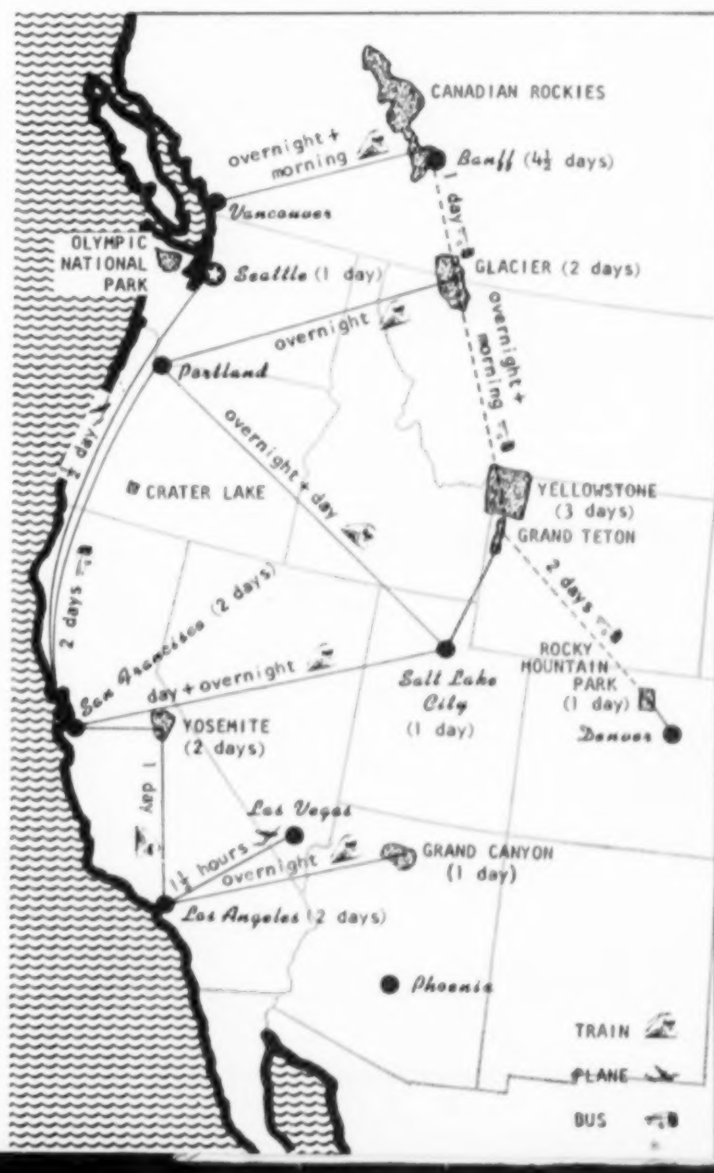
Nuclear training for chemical engineers—What do you think the Universities should do?

Tracing chemical reactions—with tagged atoms.

Filtration—rotary filter operation, correlation of cake moisture. Prediction of cake resistances and particle-size retentions. A test leaf that's new. Summary of nonwoven media.

Calcining in an agitated trough.

(*Continued on page* 104)



Acquaint yourself with
SEATTLE

(Continued from page 103)

Organic Solvent Extraction of inorganics—use of packed towers.

Computer calculations—session on preparation of data.

Dow's use of computers—an up-to-date report.

Ejector Design—using computer.

Plus—a "calculus refresher," papers on kinetics, distillation, ion exchange.

Special Note: The paper "Production of Heavy Water," by Bebbington and Thayer of DuPont, has been temporarily withdrawn from the meeting in accordance with a court order issued April 10 by the U. S. District Court for the District of Columbia, restraining the A.E.C. from divulging information on Dana or Savannah River plant heavy water process technology. The purpose of the court order is to permit the filing of application for patents. A hearing is to be held May 28, and if the information is to be freed for general release by the court as expected, the paper will be given as originally planned.

Aid in Planning Your Western Vacation

CEP offers this aid for planning your vacation in the West. It is gauged for those who can take anywhere from a few days to two weeks or more.

The map contains the highlights. If you drive out, just plan your own route. If you don't drive, here are some hints:

Glacier National Park. From Portland overnight on the evening train and spend two days in Glacier. Evening train to Chicago, or bus out on a never-to-be-forgotten trip up to Banff or down to Yellowstone and on to Denver.

Banff and Lake Louise: One-day steamer up Puget Sound to Vancouver. Night train from Vancouver travels through Rockies in morning, arrives Lake Louise in afternoon, four and a half days are spent at the Lake and Banff before evening train to Chicago. By plane to Banff is a 3-hour trip to Calgary from Vancouver, bus up to Banff. (Bus trip for the intrepid from here down to Glacier, Yellowstone, and Denver.)

Yellowstone, Grand Teton, Jackson Hole: Evening train from Portland arrives Salt Lake City next evening (plane—5 hours). Tour unique Salt Lake City one day, overnight train to Yellowstone. Three days at Yellowstone, evening train for Chicago. (Or by bus to Denver and Rocky Mountain National Park—2 days. Or

(Continued on page 106)

Acquaint yourself with SEATTLE

(*Continued from page* 104)

train back to Salt Lake City.) Jackson Hole and Grand Teton are only a half-day or less away from Yellowstone.

San Francisco, Los Angeles, Yosemite, Grand Canyon. From Seattle on afternoon train, in San Francisco by morning. (Plane—3 hr.). See San Francisco, side-trip to Muir Woods, Giant Redwood Trees. For Yosemite, train leaves San Francisco in morning, arrives by afternoon. Two days in Yosemite. Train goes on to Los Angeles. (Plane from Seattle to L.A.—6 hr.; from San Francisco to L.A.—3 hr.) See Los Angeles. Grand Canyon is overnight train from L.A. with a day at the Canyon before evening train to Chicago, or back to L.A. From Los Angeles it is 1½ hr. by plane to Las Vegas—don't plan for week end at Vegas, it is overcrowded far in advance.

OPENING DATES FOR NATIONAL PARKS

Yosemite	All year round
Grand Canyon	All year round
Banff	May 24
Jasper (Canada)	June 10
Lake Louise	June 14
Crater Lake	June 15
Glacier	June 15
Yellowstone	June 17
Jackson Hole	June 17
Grand Teton	June 17

Pacific Shore Trip. For those who have only a few days, or the time to be leisurely, an excellent trip is by bus from Portland down the Coast road to San Francisco. The morning bus is the one with an overnight stop at Eureka or Crescent City, both on the shore. (There is a bonus on this trip, or for anyone who wants to tour San Francisco. The airlines will accept a round-trip ticket between the East to Seattle for a plane ride from Seattle to Portland, and from San Francisco back east, for the same fare. So if you want to pay no extra charge, just take the scenic bus trip from Portland to San Francisco. If you want just to see San Francisco, the airlines will fly you from Portland to San Francisco for only $14 more on your round-trip ticket.)

Crater Lake: On the bus or car trip down the Coast from Portland to San Francisco, a beautiful side trip is Crater Lake National Park.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EXCHANGERS

INSTITUTIONAL NEWS

INDUSTRIALIZING THE ATOM—THEME OF 1958 NUCLEAR CONGRESS

The 1958 Nuclear Congress, to be held at Chicago's International Amphitheater March 17 through 21, will have the theme of Industrializing the Atom.

Plans are well underway now, sessions are tentatively scheduled to cover economics, finance, future plans, and much more.

Co-ordinated by EJC, and managed this year by A.I.Ch.E., the Congress will again feature, in addition to its major technical program, the Atomic Exposition, the Hot Laboratories and Equipment Conference, and the National Industrial Conference Board's Atomic Energy in Industry Conference.

At the last Congress in Philadelphia 158 papers were presented. This time the Congress Committee wants more, urges all scientists and engineers in the field of nuclear energy to contribute. Deadline for abstracts is June 15, 1957. Authors should get in touch with the *secretaries of their own societies*, or the society most closely connected to the field of their subject, rather than with EJC. Membership in EJC is not necessary, all societies are urged to participate.

Anticipating the advances a year can bring to an industry growing as rapidly as the nuclear energy industry, the 1958 International Atomic Exposition at the Congress is expected to be bigger, better and more practical than ever.

A study of surface properties and the aggregation of matter as related to liquid-solids separation will be made at the Univ. of Rochester under terms of a research contract from four companies: Bowser, Inc., and its three subsidiaries—Process Filters of Buffalo, S. F. Bowser Co. of Hamilton, Ontario, and Briggs Filtration Co. of Washington, D. C. Direction of the research project is under S. A. Miller, professor of chemical engineering. □

The third annual Oklahoma High School Engineering and Science institute has been set for June 17-July 5 at Oklahoma A&M in Stillwater. Course work in the three-week program is concentrated in three principal fields: mathematics, physical sciences and their relation to engineering, and the nature of the various fields of engineering. □

INSTITUTIONAL NEWS

A new summer laboratory program for industry is being offered by Brooklyn Polytechnic Institute. Duration is June 3 to August 12. Subjects are: X-ray diffraction, infrared spectroscopy, new electrolytic techniques, new polymerization techniques and stereospecific polymers, and ion exchange resins and membranes. ☐

The American Sanitary Engineering Intersociety Board has extended the deadline date for the receipt of applications to be considered for certification without examination so that members of A.I.Ch.E., which has just been voted a sponsor of the board, can have time to submit their applications. The new deadline is October 1, 1957. For applications and additional information write: F. B. Elder, secretary, American Sanitary Engineering Intersociety Board, Inc., 33 West 39th Street, New York 18. The three A.I.Ch.E. representatives elected to the Board are: W. L. Faith, R. F. Weston, and K. S. Watson. ☐

Two courses in Nuclear Engineering will be given this summer at the Univ. of California at Berkeley. From July 1 to Aug. 30 the Nuclear Engineering Short Course will make available a brief and intensive course in the basics of nuclear energy and its applications to industry. July 8-12 the Nuclear Engineering Survey Course will give a series of lectures for businessmen as well as engineers and scientists. ☐

A major Heat Transfer meeting will be held at Penn. State Univ. in August under the joint sponsorship of A.I.Ch.E. and AME. ☐

The 40th Annual Conference of the Chemical Institute of Canada will be held at the University of British Columbia, Vancouver, B.C., June 3, 4 and 5, 1957. Technical papers will be given on various phases of chemical engineering, chemical education, protective coatings, and other subjects. ☐

A Council for Atomic Age Studies has been created at Columbia University. Objective of the Council is to make Columbia a center for the study of problems facing society as a result of the development of atomic energy, problems which in many instances overlap a number of fields of activity and branches of learning. Areas of study represented on the Council include Engineering, Physics, Medicine, International Relations, Journalism, Business, Philosophy, and Law. ☐

INSTITUTIONAL NEWS

This modern building, costing $450,000 when fully equipped, is the new Chemical and Petroleum Engineering building of the University of Southern California's College of Engineering. Still in construction, the new building will be the second of four planned to make up an "Engineering Quadrangle."

More than 2,000 members and their families are expected for the 65th Annual Meeting of the American Society for Engineering Education to be held this year from June 17 to 21 at Cornell Univ., Ithaca, N. Y. On the agenda will be: improving high school science preparation, increasing the supply of engineering teachers, the problems of research and research manpower in engineering colleges, and more efficient use of colleges' limited facilities and staff. □

MIT will offer summer courses in Nuclear Reactor Technology (June 24 through July 5); Principles of Radioisotope Utilization (July 8 through July 19); and Organization for Research and Development (June 17 through June 28). For further details contact MIT. □

The 30th International Conference for Applied Chemistry will be held Sept. 17 to 24 in Athens, Greece. Anyone interested in attending this important meeting should get further information from F. J. Van Antwerpen, secretary of A.I.Ch.E. □

A group of courses in Management Science and Computer Technology will be presented concurrently at the Univ. of Michigan, Ann Arbor, Mich., from August 19-30. □

A gift of $5 million has been made to the University of Houston for a new College of Engineering building. The gift was made by Mr. and Mrs. Hugh Roy Cullen through the Cullen Foundation. □

Important on the list of expansions planned in Carnegie Tech's $24,350,000 expansion program is a new Engineering and Science Building. □

Chempump minimizes downtime...

pumping bulk nitric acid from delivery truck to customer's storage tank

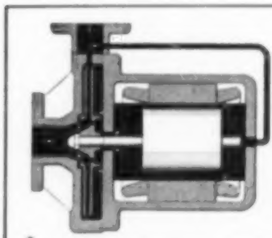
The *Chempump* mounted on this truck can't possibly leak.

For Pressure Vessel Service, Detroit, this simple fact means a considerable saving in truck downtime and maintenance in the delivery of 63% nitric acid to electroplating plants.

The conventional pump formerly used on this truck persistently leaked acid through its stuffing box. The company faced expensive repair or replacement of the acid-corroded truck bed. Pump maintenance was a continual, bothersome expense. Truck downtime was becoming a serious and costly problem.

Now, with a *Chempump* on the job, leakage is eliminated and maintenance is limited to a simple monthly inspection of pump bearings. No external lubrication is needed—bearings are constantly lubricated by the pumped fluid itself.

In any chemical handling application, *Chempump* offers many major advantages. You'll do well to check them. Write to Chempump Corporation, 1300 East Mermaid Lane, Philadelphia 18, Pa. Engineering representatives in over 30 principal cities in the United States and Canada.



Chempump combines pump and motor in a single leak-proof unit. No shaft sealing device required.

U.L. approved. Available in a wide choice of materials and head-capacity ranges for handling fluids at temperatures to 1000 F. and pressures to 5000 psi.

Chempump

First in the field...process proved

ASEE to make comprehensive survey of education of

ENGINEERING TECHNICIANS

The need for as many as 80,000 more engineering technicians a year has prompted the American Society for Engineering Education to embark on a large-scale, detailed survey of Technical Institute Education. Too many engineers, ASEE finds, are being forced to do work properly the province of the technician. More technicians are vital if the engineer is to be free to do the higher level work for which he has been trained.

In outlining its proposed survey, ASEE emphasizes, "The area of educational effort and manpower utilization represented in the engineering and scientific technician is one of currently critical and rapidly growing importance to the nation as a whole."

Technological progress, ASEE points out, is the product of "teamwork," where the team comprises the scientists, the engineers, and the engineering technicians. The research scientist turns up the new ideas, the engineers make them effective by creating designs and working out the procedures necessary to make the ideas serve human needs, and the engineering technicians complete the work by building, testing, operating, and servicing the complex creations of the engineers. Each part of the team is vital if it is to function properly.

But today, "too many engineers now find themselves required to do the work of engineering technicians, whereas they should be free to function at the higher level for which they were educated." Such a misapplication of manpower, at a time when engineers are in critically short supply, can only work to the detriment of the country.

Needed—More Technicians

Figures gathered by ASEE show that while we need some 30,000 to 40,000 engineering graduates each year, and are getting only about half, we need two or three engineering technicians for every engineer and are graduating less than one-third of

(Continued on page 116)

INSTITUTIONAL NEWS

ENGINEERING TECHNICIANS

(Continued from page 114)

what we need. This could mean as many as 80,000 a year needed.

But, to date, ASEE has found, training for engineering technicians has been diverse in method, individual in nature, and influenced more by local expediency than by long-range objective. Planning is going to be required, the coordination of effort among industry, the technical sciences, the schools and colleges, the professional societies, to make education at the technical institute level more effective and more productive.

As a first step, ASEE feels, a survey must be made to determine exactly what the present situation is.

The Technical Institute

Occupationally, the engineering technician performs semi-technical functions largely upon his own initiative and under only general supervision of a professional engineer.

Educationally he is on the level of the "technical institute," which means the intermediate strata of technological curricula which are from 1-3 years duration beyond the high school. The programs of instruction are similar to professional engineering training, but briefer and more directly technological and empirical. On the other hand, these courses of instruction are not concerned only with the acquisition of manual skills, but with principles of math and science, although more in the applied sense than in full engineering education.

ASEE Survey

The purpose of ASEE's survey will be to collect and correlate facts, opinions, and philosophies reflecting the present status and trends in technical institute level education. The last previous study of a comparable nature was made in 1928-29 by ASEE, with the help of a Carnegie Corporation grant.

General contact will be made with all possible educational institutions in the field by use of a questionnaire, and by direct visits on a sampling basis. Industry, which performs much of the training in this area, will be contacted by direct visits. The survey will be conducted on a regional basis, and actual visits will be made by men well qualified in the field of technical institution education. The study will again be aided by a Carnegie Corporation grant of $38,000.

FUTURE MEETINGS

View of Seattle from Queen Anne Hill, Mt. Rainier in background.

■ **SEATTLE, WASH.** June 9-12, 1957. Olympic Hotel. See page 102 for meeting details.

■ **ST. LOUIS**

June 2-6, Jefferson Hotel.

Golden Anniversary Meeting, Air Pollution Control Association. Sponsoring Societies: A.I.Ch.E., A.S.M.E., Amer. Soc. of Heating and Air Conditioning Engineers, Amer. Meteorological Soc. Program covers:

Methods of Analysis; Instrumentation; Atmospheric Reactions, Photochemical & Other; Aerosol Formation & Control; Progress in Air Pollution Control Equipment & Methods; and Human & Economic Goals for Engineers in Air Pollution Control will be treated.

Papers sponsored by A.I.Ch.E.:

June 4, 1957, A.M.: **Chemical Engineering Aspects of Air Pollution Control,** M. Sittenfield, Marcus Sittenfield and Assoc. **Sources and Control of Sulfur Bearing Pollutants,** H. W. Nelson and C. J. Lyons, Battelle. **Emissions from Organic Solvent Usage in Los Angeles County,** R. G. Lunche, C. J. Seymour, A. Stein and R. L. Weimer, Los Angeles County Air Pollution Control Dist. **The Role of Motor Vehicle Exhaust in Smog Formation,** W. L. Faith, Air Pollution Foundation.

June 4, 1957, P.M.: **Disposal of Gaseous Effluents from Nuclear Power Plants,** G. F. Jenkins, Union Carbide Nuclear. **Methods of Evaluation of Dust Collection Equiupment,** K. E. Lunde and C. E. Lapple, Stanford Research Inst. **Continuous Instrumentation for Atmospheric Analyses,** L. H. Rogers, Air Pollution Foundation.

Banquet—Tuesday, June 4, 7:00 P.M.

■ **PASADENA, CALIF.**

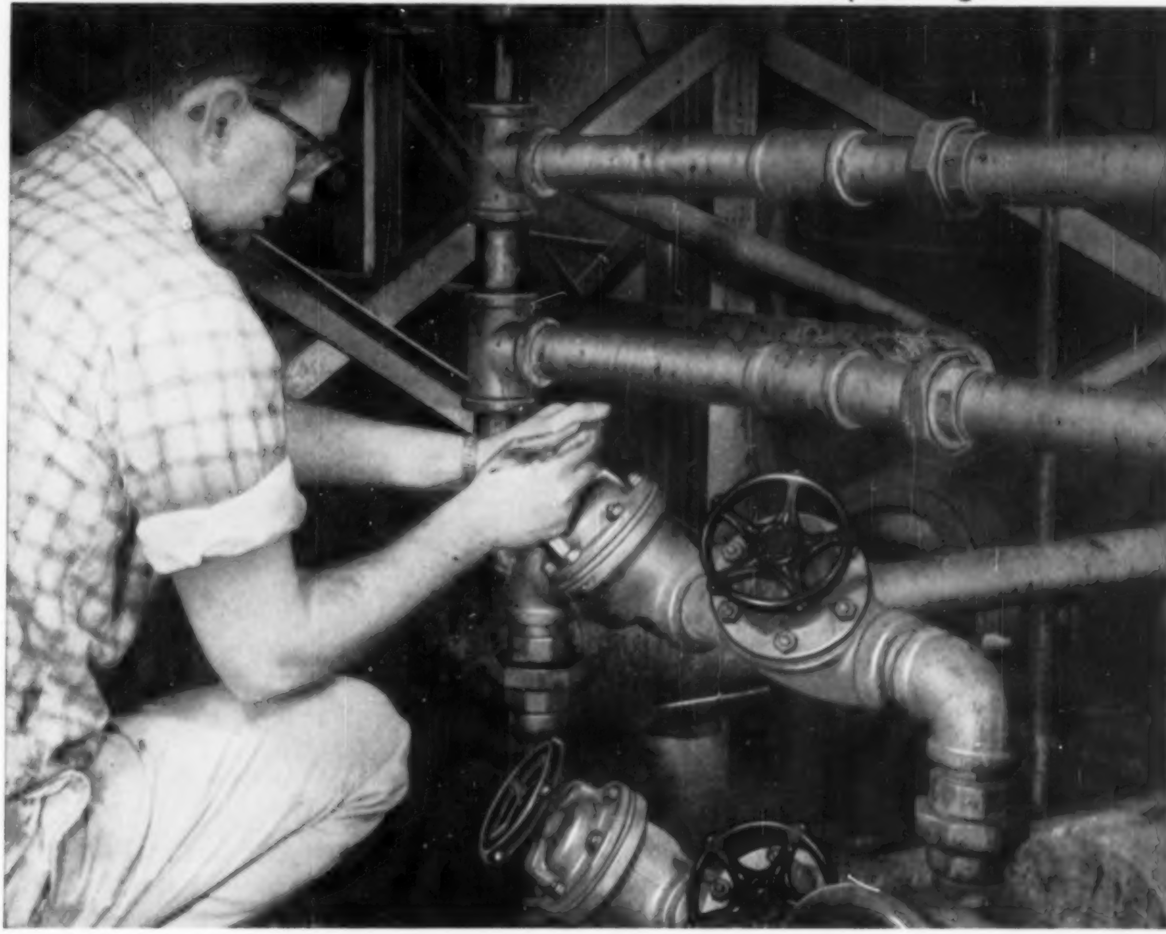
June 19-21, 1957. California Institute of Technology.

The 1957 Heat Transfer and Fluid Mechanics Institute. A.I.Ch.E. is one of the sponsoring societies. Papers on technical and scientific advances in fluid mechanics, heat transfer, thermodynamics, and related fields.

Papers to be presented: **Ignition in Transient Flows,** D. Bitondo, N. Thomas, D. Perper, Aerophysics Devel. Corp. **Heat Transfer to Surfaces in the Neighborhood of Protuberances in Hypersonic Flow,** M. H. Bloom, A. Pallone, Brooklyn Polytechnic. **Cooling of Solid Surfaces with Heat Power Inputs Over 10^{n} Watts/sq.cm.,** D. E. Bloxsom, Jr., Marquardt Aircraft Co. **General Properties of Normal Shock Waves at Hypersonic Speeds,** J. C. Bradley, Rias, Inc. **Experimental Investigation of Mass Transfer by Sublimation from Sharp-Edged Cylinders in Axisymmetric Flow with Laminar Boundary Layer,** W. J. Christian, Armour Research Found. and S. P. Kezios, Ill. Inst. of Tech. **The Laminar Boundary Layer Near a Sonic Throat,** D. Coles, Calif. Inst. of Tech. **Ignition in the Laminar Boundary Layer of a Heated Plate,** D. Dooley, Aeronutronics Systems, Inc. **The Chemical**

(Continued on page 122)

Another satisfied user of Crane Diaphragm valves



Best by test for this heavy, sticky emulsion —Crane diaphragm valves

What valve is best and lasts longest in this service? A West Coast emulsified asphalt producer tried them all on the manifold above and here's what was found.

Conventional valves would become inoperative in a short time. The main trouble was binding of the stem in contact with the cold, heavy asphalt emulsion.

Ordinary diaphragm valves on the same service lasted only two months and had to be replaced. The diaphragms didn't stand up and the high torque required for closure was impractical for frequent operation.

Three years ago the plant started using Crane No. 1610 Packless Diaphragm Valves. The neoprene diaphragm functions only to seal the bonnet. It is not subject to crushing and excessive wear as a seating member. The separate disc in combination with Crane Y-pattern body makes positive closure with minimum torque and turns. These valves are giving full satisfaction.

Literature on Request

Wide choice of body and diaphragm materials makes these exclusive Crane valves particularly useful to process industries. Ask your Crane Representative for Circular AD-1942, or write to address below.

CRANE VALVES & FITTINGS

PIPE • PLUMBING • KITCHENS • HEATING • AIR CONDITIONING

Since 1855—Crane Co., General Offices: Chicago 5, Ill. Branches and Wholesalers Serving All Areas

AUDITOR'S REPORT

We have examined the balance sheet of the American Institute of Chemical Engineers as of December 31, 1956 and the related statement of income and surplus for the year then ended. Our examination was made in accordance with generally accepted auditing standards, and accordingly included such tests of the accounting records and such other auditing procedures as we considered necessary in the circumstances.

In our opinion, the accompanying balance sheet and statement of income and surplus present fairly the financial position of the American Institute of Chemical Engineers at December 31, 1956, and the results of its operations for the year then ended, in conformity with generally accepted accounting principles applied on a basis consistent with that of the preceding year.

F. W. LAFRENTZ & CO.
Certified Public Accountants

AMERICAN INSTITUTE OF CHEMICAL ENGINEERS

BALANCE SHEET
DECEMBER 31, 1956

Assets

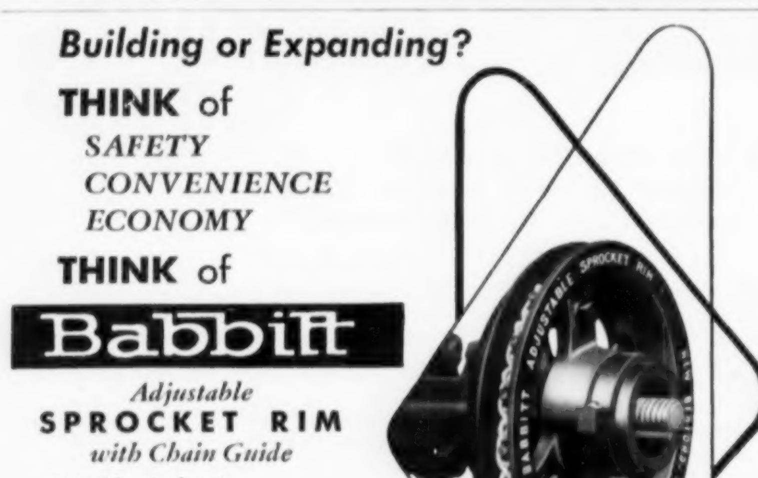
Current assets:		
Cash on hand and demand deposits	$128,187.94	
Cash in savings institutions	116,309.45	
Total	$244,497.39	
Less cash in research and Bowman funds	48,040.13	$196,457.26
Investments, at cost including accrued interest	$172,308.46	
Less investments in Marshall and Bowman Funds	4,000.00	168,308.46
Accounts receivable, net		46,778.40
Inventory, at cost		13,580.46
Prepaid expenses		4,488.98
Total current assets		$429,613.56
Deposits at airlines, post office, etc.		1,740.53
Total		$431,354.09
Trust and Special Funds:		
Albert E. Marshall Fund	$ 3,000.00	
Frederic C. Bowman Fund	1,118.35	
Research Committee Fund	47,921.78	52,040.13
Total		$483,394.22

Liabilities

Current Liabilities:	
Accounts payable	$ 28,816.04
Deferred income	169,752.97
Reserve for participation fee—United Engineering Trustees, Inc.	50,000.00
Education and preprint funds	2,773.88
Surplus	180,011.20
Total	$431,354.09
Trust and special funds (as set forth above)	52,040.13
Total	$483,394.22

STATEMENT OF INCOME AND SURPLUS
FOR THE YEAR ENDED DECEMBER 31, 1956

Income:		
Membership dues	$259,203.08	
Less allocation to subscriptions	67,547.62	$191,655.46
Membership entrance fees		11,303.00
Publications		512,187.80
Nuclear Engineering Congress and Atomic Exposition		12,451.31
Investment		6,017.55
Unexpended appropriation, Special Task Committee, engineering center		8,428.58
Total		$742,043.70
Expenses:		
Publications		$251,426.70
Salaries and commission		306,111.77
Retirement plan and federal insurance contributions		8,252.37
Rent and electric		18,528.74
Office equipment		10,647.31
Printing, stationery and supplies		23,982.71
Postage, telephone and telegraph, auditing and insurance		22,923.93
Meetings		7,798.20
Travel		4,399.85
Awards		1,557.77
Committees		7,660.70
Participation in professional groups		5,685.59
E.C.P.D.—E.J.C. Survey		3,000.00
Engineering center survey		10,000.00
Miscellaneous		9,654.97
Total		$691,630.61
Net income for year		$ 50,413.09
Surplus, December 31, 1955	$179,598.11	
Less amount appropriated for participation fee, United Engineering Trustees, Inc.	50,000.00	129,598.11
Surplus, December 31, 1956		$180,011.20



FUTURE MEETINGS

(Continued from page 118)

Kinetics of Air at High Temperatures: a Problem in Hypersonic Aerodynamics, S. Feldman, AVCO Mfg. Co. **The Heat Balance Integral and its Application to Problems Involving a Change of Phase,** T. R. Goodman, Allied Research Assoc. **Some Problems of Laminar Boundary Layer Shock Wave Interaction,** I. Greber, R. J. Hakkinen, L. Trilling, MIT. **On the Instability of Small Gas Bubbles Moving Uniformly in Various Liquids,** R. A. Hartunian, W. R. Sears, Cornell Univ. **Emissivity of High Temperature Air,** J. Keck, B. Kivel, T. Wentink, Jr., AVCO Research Lab. **Inviscid Hypersonic Flow Over Blunt-Nosed Slender Bodies,** T. Kubota, Calif. Inst. of Tech. **Transformation of the Compressible Turbulent Boundary Layer,** A. Mager, Marquardt Aircraft Co. **Analysis of Steady, Finite-Amplitude Cellular Flames,** G. H. Markstein, Cornell Aeronautical Lab. **The Unsteady Laminar Boundary Layer of a Wedge, and a Related Three-Dimensional Problem,** F. K. Moore, Cornell Aeronautical Lab. **The Sound Generated by Interaction of a Single Vortex with a Shock Wave,** G. I. Ram, H. S. Ribner, Univ. of Toronto. **An Investigation of Stagnation Point Heat Transfer in Disassociated Air,** P. H. Rose, F. R. Riddell, AVCO Research Lab. **The Fluid Flow Associated with the Impact of Liquid Drops with Solid Surfaces,** P. Savic, G. T. Boult, Nat. Research Lab. **Some Effects of Isotropic Turbulence on a Pendulum at Moderate Reynolds Number,** W. H. Schwarz, Stanford Univ.; S. Corrsin, Johns Hopkins Univ. **The Influence of Solid Body Rotation on Screen-Produced Turbulence,** S. C. Traugott, H. Yeh, Univ. of Penn.

Invited Speakers: D. Fultz, Depart. of Meteorology, Univ. of Chicago, **Fluid Mechanical Characteristics of Large-Scale Meteorological Problems Illustrated by Experiment.** E. R. G. Eckert, Depart. of Mech. Eng., Univ. of Minn., **Research in Continental Europe in Engineering Thermodynamics and Heat Transfer.**

Banquet: Thursday, June 20.

■ **STATE COLLEGE, PA.**

August 11-14, 1957. Pennsylvania State University.

First National Conference on Heat Transfer. Sponsors: A.I.Ch.E. A.S.M.E., & College of Eng. & Arch., Penn State Univ. Purpose is to provide a forum and an opportunity to exchange ideas and data on the industrial applications of heat transfer. Details of program will be published in June issue of CEP.

A.I.Ch.E. program chairman is James N. Addoms, Atlas Powder Co., Wilmington 2, Del.

■ **CLEVELAND, OHIO**

September 7-13, 1957, Cleveland Auditorium. Annual Instrument-Automation Conference & Exhibit of the Instrument Society of America. Conference theme will be "Instrumentation for Systems Control." Educational aspects will be emphasized. A.I.Ch.E. members are invited to register at same rate as ISA members.

■ **BALTIMORE, MD.**

September 15-18, 1957. Lord Baltimore Hotel

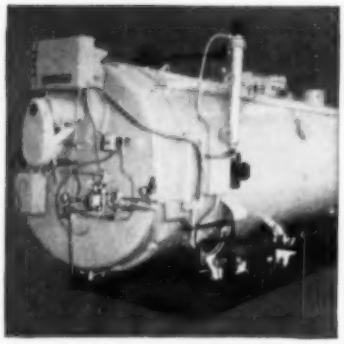
TECHNICAL PROGRAM CHAIRMAN: R. L. Copson, Mutual Chemical Co. of America, 1348 Block St., Baltimore 31, Maryland.

Adsorption, Dialysis, and Ion Exchange

Intended to furnish basic information for chemical engineers working on mass separation problems.

(Continued on page 124)

Flintkote applies asphalt at 485°F.



A horizontal vaporizer (above) is used by Flintkote. Low pressure performance (144 p.s.i. at 750°F.) of Dowtherm permits the use of compact, thin-walled equipment.

Dowtherm (Dow heat transfer medium) makes precise process temperature (±1°F.) possible with no coking or carbonization

Applying asphalt at 485°F. is a hot job. And when the temperature can't vary more than a few degrees F., *it's a hot problem!* And that was the problem facing The Flintkote Company in Chicago Heights, Illinois.

To obtain the required temperature control, Flintkote decided to invest in an entirely closed heating system using Dowtherm® as a vapor heating medium.

With Dowtherm they found they could use more compact and thinner-walled equipment. Fraction-of-a-degree temperature accuracy was easily maintained. With the heating source far from the processing area, they practically eliminated any problem of burning asphalt. Dowtherm also completely did away with "hotspots"—providing more uniform heating and at the same time cutting down on equipment cleaning time.

Manufacturers of closed heating systems using Dowtherm will gladly study your heating process. They will design equipment to fit your needs. For more information about this interesting, useful and economical product, call us. We'd be delighted to meet you. THE DOW CHEMICAL COMPANY, Midland, Michigan, Dept. BD 846J.

YOU CAN DEPEND ON DOW

FUTURE MEETINGS

(*Continued from page* 122)

MEETINGS **SYMPOSIA**

Jet Propulsion

Emphasis will be on manufacture of chemical fuels. One paper on application to Earth Satellite program.

The Alkali-Chlorine Industry

A management symposium on technological problems, trends, and end uses.

Drying

Aspects of industrial drying, including spray drying techniques.

Low Temperature Processing

The second symposium on this subject following an introductory session at the last Boston meeting.

Direct Operating Labor Costs

Featuring an industrial engineering approach to estimation of labor costs.

Air Plant Safety

A panel discussion with a planned agenda.

Ammonia Plant Safety

A panel discussion with a planned agenda.

■ ANNUAL—CHICAGO, ILL.

December 8-11, 1957. Conrad Hilton Hotel

TECHNICAL PROGRAM CHAIRMAN: Henry F. Nolting, Standard Oil Co., 2400 New York Ave., Whiting, Ind. Those interested in submitting papers for consideration should address themselves directly to the chairman of the appropriate session.

Fluidization of Solids

CHAIRMAN: E. R. Gilliland, Chem. Eng. Dept., M.I.T., 77 Massachusetts Ave., Cambridge 39, Mass.

Effective Cost Control in Process Operations

CHAIRMAN: C. W. Nofsinger, The C. W. Nofsinger Co., 906 Grand Ave., Kansas City 6, Mo.

Evaluation of Projects from the Original Idea to the Investment Stage

CHAIRMAN: C. W. Nofsinger (see above).

Chemical Engineering Abroad

CHAIRMAN: Shelby Miller, Chem. Eng. Dept., University of Rochester, River Campus Station, Rochester 20, N. Y.

Corrosion Resistant Alloy Materials of Construction

CHAIRMAN: G. Fred Ours, Carbide and Carbon, Charleston, W. Va.

Laboratory and Pilot Plant Techniques

CHAIRMAN: G. W. Blum, The Goodyear Tire & Rubber Co., 1485 E. Archwood Ave., Akron 16, Ohio.

Production of Heavy Water

CHAIRMAN: W. Bebbington, du Pont Savannah River Project, Savannah River, Ga.

Radiation Processing

CHAIRMAN: J. J. Martin, Dept. of Chem. Eng., Univ. of Michigan, Ann Arbor, Michigan.

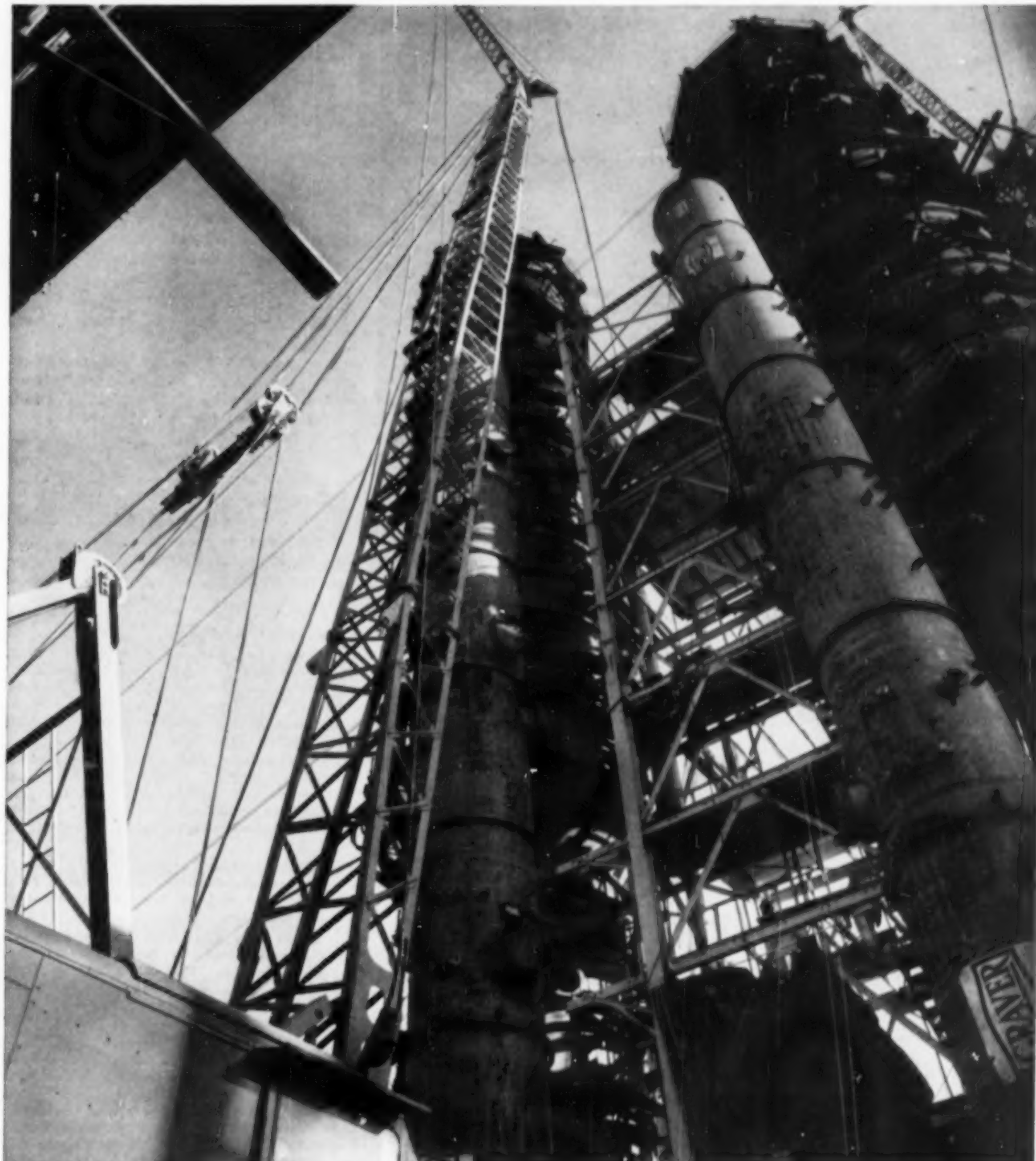
Nuclear Process-Heat and Radiation Source Reactor Systems for the Chemical and Metallurgical Industries

CHAIRMAN: B. W. Gamson, Borg-Warner Corporation, Des Plaines, Illinois.

Extractive Metallurgy

CHAIRMAN: B. W. Gamson (see address above).

(*Continued on page* 126)



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HOUSTON • LOS ANGELES • FONTANA, CALIFORNIA • SAN FRANCISCO

FUTURE MEETINGS

(Continued from page 124)

MEETINGS **SYMPOSIA**

Selling a Technical Program
CHAIRMAN: W. L. Bulkley, Standard Oil Company (Ind.), Whiting, Indiana.

Shock Waves in Process Equipment
CHAIRMAN: Stuart Churchill, Dept. of Chem. Eng., Univ. of Michigan, Ann Arbor, Michigan.

Impact of Computers on the Practices of Chemical Engineering
CHAIRMAN: Leon Cooper, Monsanto Chemical Company, St. Louis, Missouri.

The Separation of Materials in Biological Processes
CHAIRMAN: Elmer Gaden, Dept. of Chem. Eng., Columbia University, New York City.

Chemicals Recovery in the Paper Industry
CHAIRMAN: R. P. Whitney, Inst. of Paper Chemistry, Appleton, Wisconsin.

Process Application of Reactors
CHAIRMAN: J. J. Martin, Univ. of Michigan, Dept. of Eng., Ann Arbor, Michigan.

1958 MEETINGS

- Montreal, Canada, April 20-23, 1958. Sheraton-Royal Hotel. Joint A.I.Ch.E.-C.I.C. Conference. A.I.Ch.E. CHAIRMAN: Kenneth Beatty, North Carolina State College, Raleigh, N. C. CO-CHAIRMAN: W. H. Gauvin, McGill University, Montreal.
- Philadelphia, Pa. June 22-27, 1958. Bellevue-Stratford Hotel. A.I.Ch.E. Fiftieth Anniversary Meeting. CHAIRMAN: Roy Kinckiner, DuPont, Wilmington, Del. See further details of meeting and program listed below.
- August 18-21, 1958. A.I.Ch.E.-A.S.M.E. Heat Transfer Conference. CHAIRMAN: A. S. Foust, Dept. of Chem. Eng., Lehigh University, Bethlehem, Pa.
- Salt Lake City, Utah, September 21-24, 1958. CHAIRMAN: E. B. Christiansen, Dept. of Chem. Eng., Bldg. 437, Univ. of Utah, Salt Lake City. **Air Pollution**—CHAIRMAN: W. L. Faith, Air Pollution Foundation, 704 S. Spring St., Los Angeles 14, California.
- Cincinnati, Ohio, December 7-19, 1958. Netherland Plaza Hotel. A.I.Ch.E. Annual Meeting. TECHNICAL PROGRAM CHAIRMAN: A. C. Brown, Emery Industries, Inc., June & Long Streets, Ivorydale, Ohio. **Water Pollution**—chairman to be named. **Distillation**—CHAIRMAN: W. C. Schreiner, M. W. Kellogg Co., 711 Third Ave., New York 17, N. Y. **High-Speed and Time-Lapse Photography in Chemical Engineering**—CHAIRMAN: J. W. Westwater, William Albert Noyes Laboratory, Univ. of Illinois, Urbana, Ill.

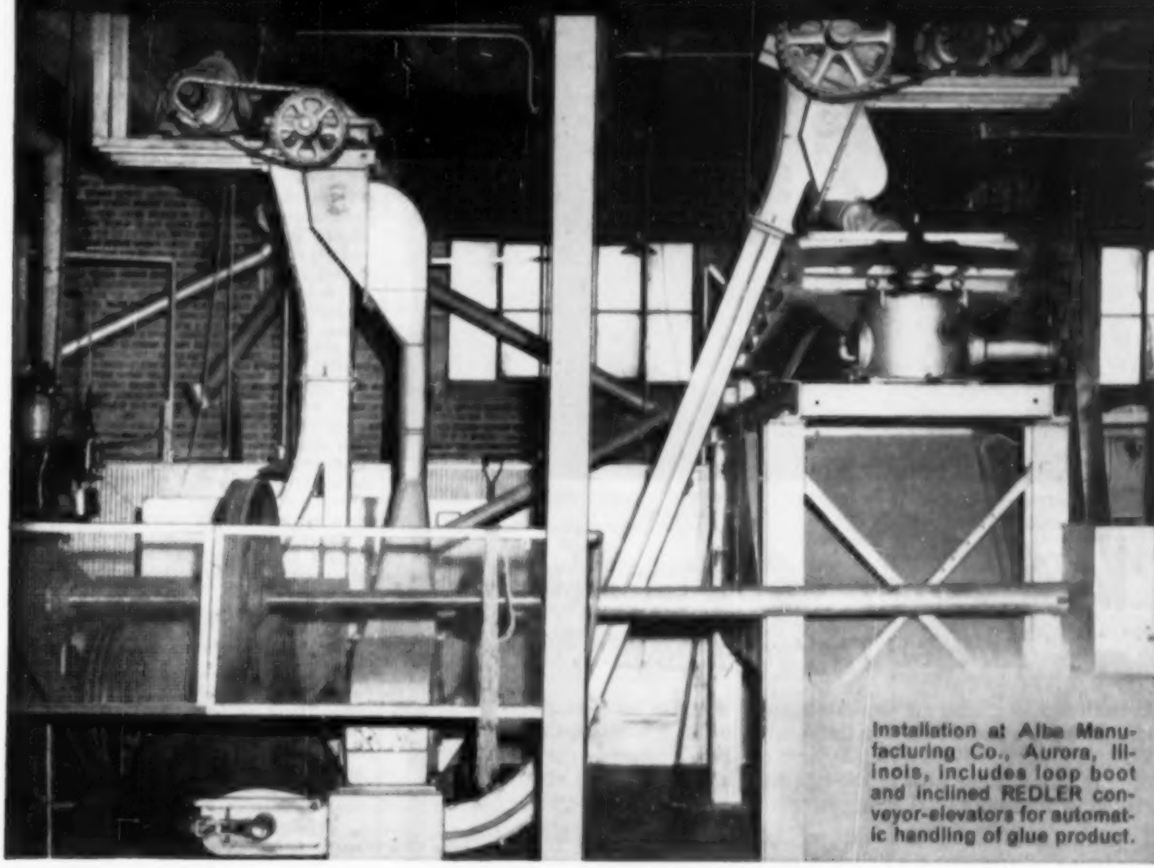
FIFTIETH ANNIVERSARY MEETING

Philadelphia, Pa. June 22-27, 1958. Bellevue-Stratford Hotel. A.I.Ch.E. 50th Anniversary Meeting. CHAIRMAN: Roy Kinckiner, DuPont, Wilmington, Del. Theme for program is: **A Look to the Future.** All symposia and papers are being planned in accordance with this theme. Broad areas of chemical engineering will be covered as follows:

- **One group** of papers will review briefly

(Continued on page 128)

STEPHENS-ADAMSON



Installation at Alba Manufacturing Co., Aurora, Illinois, includes loop boot and inclined REDLER conveyor-elevators for automatic handling of glue product.

from start to finish handle your bulk materials automatically

Obviously, to push forward with increased production, you need automatic aids—mechanical conveying that speeds processing by eliminating back-breaking tasks, wasted motion, and excessive handling.

Conveying equipment to handle every conceivable dry bulk material, and the engineering ability to apply it correctly, has made the big name of STEPHENS-ADAMSON one the chemical processing industry can rely on. Due to vast engineering and manufacturing experience, the S-A way of bulk material handling is the surest way of keeping production in your plant at the highest level while holding down handling costs.

Whenever your raw or processed materials can be handled in bulk form, it is the most economical way. Let the S-A engineer in your area show you why.

A belt conveyor and tripper by Stephens-Adamson handles Ammonium Sulphate for National Aniline Div. of Allied Chemical and Dye Corp., Hopewell, Va. The tripper is self-propelled, discharging an 18-inch belt along a 352-foot run over storage hoppers.

Vital potash fertilizer is loaded into box cars by this STEPHENS-ADAMSON Swiveloader. It is part of a complete handling system and insures maximum uniform loading by throwing potash to far corners of the car.

S-A manufactures a wide range of material handling products in three complete plants in U. S. and Canada.

- Belt Conveyors
- Belt, Pan & Plate Feeders
- Ship Loading Boom Conveyors
- Stacking Conveyors
- Storage & Reclaiming Systems
- "Natural Frequency" Vibrating Conveyors
- REDLER Conveyor-Elevators
- ZIPPER Conveyor-Elevators
- Conveyor Belt Cleaners
- Headshaft Holdbacks
- Grizzlies & Screens
- Centrifugal Pilers
- Bin Gates & Tunnel Gates
- Car Pullers & Spotters
- Bucket Elevators
- Skip Hoists
- SEALMASTER Ball Bearing Units

• *Write for a bulletin on any of the above products.*

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FUTURE MEETINGS

(*Continued from page* 126)

the history and early art in an introductory way, presenting a background for the papers which follow.

- **A second group** of papers will deal with the present status of the subject fields, in particular pointing out gaps in information both from the standpoint of theory and practice.
- **A third group** of papers will attempt to point out what lines of investigation can be profitably undertaken to fill the gaps in our information.

Symposia will vary in length from 4 to 8 papers, covering one or two sessions. It is not the intention of the Committee to accept papers of a character usually presented at A.I.Ch.E. meetings; time will not permit presentation of experimental results or of pieces of experimental work reported in the usual way. The Committee believes the objectives of the meeting will best be met by the author's giving the results of investigations in cases where such are necessary to meet the second and third categories (above).

It should be obvious from the plans of the Committee that authors having a reasonably broad knowledge of their respective fields should be encouraged to propose and prepare papers for the program.

To permit prepublication, which is desired by the Committee, **deadline for submission of papers to the Technical Program Committee is June 30, 1957.** Where prepublication is impracticable, the deadline is tentatively fixed at November 30, 1957. Symposia, together with responsible chairmen, are listed as follows:

- **UNIT OPERATIONS** (2 sessions)—C. R. Wilke, Univ. of Calif., Berkeley: **distillation, fractionation, absorption.** F. M. Tiller, Lamar State Coll., Beaumont, Texas: **filtration, drying, size reduction, mixing, flotation, centrifugal separation, crystallization & nucleation, classification & collection of solids.**
- **CHEMICAL ENGINEERING IN NUCLEAR FIELD**—R. P. Genereaux, DuPont, Wilmington.
- **KINETICS & REACTIONS** (2 sessions)—R. H. Wilhelm, Princeton, N. J. or N. R. Amundson, Univ. of Minnesota, Mpls.., Minn.
- **PROCESS CONTROL** (2 sessions on dynamic aspects of processes)—D. M. Boyd, Universal Oil Products, Des Plaines, Ill. & P. S. Buckley, DuPont, Wilmington.
- **MATERIALS OF CONSTRUCTION** (2 sessions)—E. M. Mahla, on metals; R. B. Filbert, Battelle, on nonmetals.
- **FUNDAMENTALS** (1 or 2 sessions)—J. L. Franklin, Humble, Baytown, Tex.
- **EDUCATION OF THE CHEMICAL ENGINEER** (3 sessions)—F. M. Tiller, academic; chairman to be selected, industrial.
- **INDUSTRIAL MANAGEMENT OF THE FUTURE** (2 sessions)—Eugene Wall, du Pont.
- Symposia under consideration: Our Institute of the Future, Chemical Engineering Economics, What Will the Next 50 Years Produce?

Comments and suggestions are invited. Proposals of papers should be directed to symposium chairman, with carbon copy to Roy A. Kinckiner.

UNSCHEDULED SYMPOSIA

Proposed, but unscheduled, symposia of the Institute may be found listed in April *CEP*, page 114. Correspondence on proposed papers is invited by the program chairmen.

SPARKLER
horizontal plate
FILTERS

Undisputed First Choice

with engineers who have had occasion to thoroughly test this type of filter. Shown here are structural features that are the result of over 30 years experience in building this one filter. If it could be made better or cheaper Sparkler would have made it that way long ago.

Aloysius C. Kracklauer
Originator of the Horizontal Plate Filter

A.S.M.E. designed construction is standard for pressures up to 60 lbs. on all filter tanks.

Plates sealed independently at center and periphery to assure positive seal.

Plates sealed independent of tank closure to secure a positive seal for both filter plates and for tank cover.

Scavenger plate supported by re-inforced flat bottom tank.

Cartridge plate assembly—removable indepently of tank.

Heavy solid plate rings precision machined.

Heavy perforated sheet metal support for filter paper.

A more positive filter seal is obtained when hydraulic pressure is applied to plates externally rather than internally.

Plate designed to reduce flow friction to a minimum.

SPARKLER FILTERS

The Sparkler, original exclusive horizontal plate design and flow principle, has never been equalled for efficiency and dependability in filtering with any and all types of filter aids. The cake maintains its original position as formed regardless of pressure fluctuation flow rate or viscosity. No break-through is possible, even with a complete shut down of the filter. Filtering can be resumed with perfect safety at any time. With Sparkler plate construction a completely sanitary filter can be furnished.

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REPRESENTATIVES IN PRINCIPAL CITIES THROUGHOUT THE WORLD

New catalysts pose new engineering problems. Here is a "refresher" to bring you up to date on

CATALYSIS IN PRACTICE

There is no easy way to find the best catalyst for a new chemical process. Evaluation of a catalyst in its ultimate form requires the development of a process based on that catalyst. It is not possible to separate the choice of a catalyst from the choice of a process. These were basic tenets cited by Kapp of Houdry in his introductory talk, "What Catalyst and Why."

In some respects, the catalyst is only another process variable such as temperature, pressure, or space rate. In other respects, the catalyst is a raw material whose cost must be kept at a reasonable level. Life and price of the catalyst are, therefore, critical factors and, in the case of attrition losses in circulating systems, catalyst makeup can be equally critical.

Catalyst usefulness may be terminated by reduced activity or by reduced selectivity. Both factors can be adversely affected by thermal sintering, by aging accelerators, and by many types of poison in the feed. Catalyst makeup rate in circulating catalyst units is sometimes used to control activity and poison levels.

In order to cope with the problems of commercialization, the development engineer must cut across section and department boundaries. He must trade information informally with chemists and engineers in research, manufacturing, and sales to obtain the facts for a proper analysis of the overall problem. Only by a judicious blend of theory, technology, and experience on catalysts and catalytic processes can he succeed in the efficient commercial development of a new catalytic chemical process.

Catalysts are chemicals. They are chemical reagents that combine with the starting materials to form compounds. Chemical changes then take place followed by decomposition into the desired product and the original catalyst.

This concept of a catalyst being a chemical reagent is an important one for both the chemist and the chemical engineer. It gives the chemist a better working picture as he searches for new catalysts or new chemical processes. For the chemical engineer, all chemical reagents impose certain conditions on the design of a plant using that reagent. Catalysts as reagents are no exception. As new catalysts are developed with more and more specialized uses, they will inevitably pose even more complicated engineering problems than they have in the past.

Thomas, Sun Oil

Based on papers presented before One Day Meeting of the Philadelphia-Wilmington Section, A.I.Ch.E., April 9, 1957. Authors: Martin Kapp, Houdry Process Corp.; F. G. Ciapetta, C. D. Helm, L. L. Baral, Davison Chemical Co.; A. B. Stiles, Du Pont; J. M. Bourguet, S. J. Wantuck, Socony Mobil Oil Co.; R. E. Reitmeier, Girdler Co.; J. M. Harris, Jr., Rohm & Haas Co.; C. L. Thomas, Sun Oil Co. (presented by C. G. Kirkbride, Sun Oil Co.).

R. E. Reitmeier, Girdler Co., addresses the Philadelphia-Wilmington one-day session on "Economics of Catalyst Use."

How Catalysts Are Prepared

The commercial procedure used in the preparation of industrial catalysts may be considered to be a combination of several unit operations, said L. L. Baral of Davison Chemical in his discussion of "Commercial Preparation of Industrial Catalysts." Such operations may include the following:

Initial preparation: In general, one starts with aqueous solutions of the desired constituents and adds the required precipitating agents. Gel formation, a special case of precipitation, is frequently employed in the manufacture of catalysts whose major components are hydrous oxides. In certain cases, advantages of the gel formation method may be:

1. Higher surface area in the final catalyst.
2. Improved control of density and porosity in the finished catalyst.
3. Easier washing of impurities from the gelled material.
4. Ease of filtration of the product.

Impregnation methods: Dispersing an active component or components on an inactive support is frequently the simplest possible method of preparing a catalyst. Such impregnation may be either liquid or vapor phase.

Special preparation methods: Thermal fusion methods are used for the preparation of certain types of catalysts such as the promoted iron catalyst used for the synthesis of hydrocarbons and ammonia.

Other chemical reactions, such as decomposition, oxidation, and reduction, are frequently employed. For example, copper chromite catalysts are prepared by the thermal decomposition of a precipitated copper ammonium chromate.

Clay catalysts, used in the catalytic cracking of gas oils to gasoline, are prepared industrially by the leaching of special clays with sulfuric acid. During the acid treatment, the alkali and alkaline earth cations are replaced with hydrogen ion, and the concentration of undesirable constituents such as iron is reduced.

Filtration and washing: Catalysts prepared by precipitation or gelation techniques require a filtration step and usually a washing step. Rotary filters, plate-and-frame filters, and centrifuges are all used, the choice being based on the usual considerations.

When a precipitate or gel possesses zeolitic properties, washing alone will not suffice to remove all contaminating ions. In such cases, an ion exchanging operation will be required prior to or during the washing procedure. Such a situation arises in the preparation of co-gelled silica-alumina cracking catalysts, the alkali metals being exchanged with ammonium or aluminum ions.

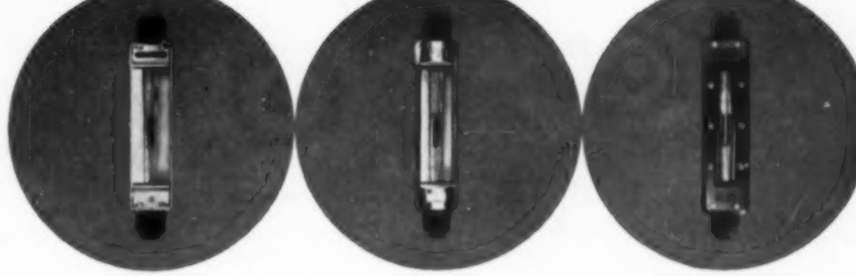
Preliminary drying: Ordinarily, preliminary drying of the catalyst is carried out in air, in electric furnaces, or in steam ovens, at temperatures between 120 and 450° F. Where the finished catalyst is produced in the form of pellets, the extent of drying may affect the ease of pelleting.

Catalyst forming or sizing: Catalysts used for liquid-phase reactions are usually ground to pass through a 100 to 200 mesh screen. Catalysts used for vapor-phase reactions in a fixed-bed reactor are most frequently used in the form of granules, pellets, or extrusions, whereas catalysts used in fluid-bed operations are usually ground to pass a 60 mesh screen. In moving-bed operations, such as the TCC cracking unit, the catalysts may be prepared in bead form to reduce attrition.

Calcination and activation: In general, all catalysts used for vapor-phase reactions are calcined and activated at temperatures above 400 to 500° F. Calcination or activation may be carried out

(Continued on page 132)

the design you want...



sideplate
Rugged general-purpose basic design. For non-hazardous uses.

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Attractive design with stainless bezel; gasketed safety glass cover.

pressure sealed
Strongest of all. Resists breakage. Contains liquid if glass ruptures.

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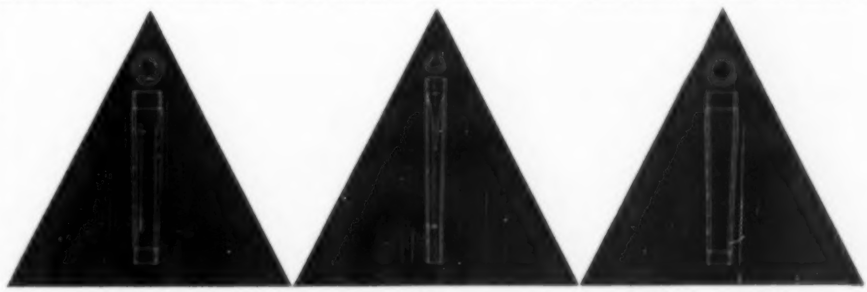

bead guide
For general use giving high accuracy over wide range.

tri-flat
For use with ball floats to meter low flow rates.

plain tapered
For special fluids and those containing solid particles.

and float...

nail head
2 types, 7 sizes for use with bead guide tubes.

ball
4 materials in 3 sizes for tri-flat tubes.

special
For highly corrosive fluids or specialty applications.

make these stainless steel enclosed flowmeters the right choice for corrosive conditions

These engineering alternatives just begin to describe the reasons why the 1700 Series variable area Flowrator meters offer the right solution to corrosion problems. Further, you can select from more than twenty different proven materials for corrosion-proof end fittings and floats. Add to this the stainless steel enclosure for all models, plus the neoprene backed Teflon packing liners, and the applications of the 1700 Flowrator are limited only by those that would affect glass.

All 1700 Series Flowrators embody proven engineering principles for measuring any flow accurately up to 200 gpm of water, 400 scfm of air. Pipe connections—horizontal or vertical, screwed or flanged—can be made from any direction through a provision for 360° rotation of connection. Full data on the 1700 Series is given in Catalog 10-A-25. For your copy, write Fischer & Porter Company, 1157 County Line Road, Hatboro, Pennsylvania.

Fp

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Complete Process Instrumentation

CATALYSIS

(Continued from page 130)

in a muffle furnace, a rotary calciner, or in a high temperature reactor. Design of equipment must provide uniform and closely controlled temperatures as well as residence times at these temperatures.

Moving vs. Fixed Bed Techniques

Most industrial catalytic processes fall into two main categories—fixed-bed and continuous systems. The continuous category can be conveniently subdivided into two further sub-categories: moving-bed and fluid processes. In the first case, the solids are sizeable particles which move through the reaction zone as a compact bed. In the other case, the solids are finely divided particles which move through the reactor as a turbulent mass agitated by the contacting vapors.

EACH SYSTEM HAS ADVANTAGES

The moving-bed technique has been widely applied to petroleum refining operations, particularly to catalytic cracking. The merits and demerits of this system were discussed at Philadelphia by Bourguet (Socony Mobil) in his paper "Moving Bed Processes," while the fixed-bed system, which still finds application to a multitude of different catalytic processing operations, was described by Stiles (Du Pont) who spoke on "Fixed Bed Catalyst Systems."

Main advantages of the fixed-bed reactor, according to Stiles, can be summed up as follows:

1. Simplicity.
2. Relatively low maintenance.
3. Avoidance of catalyst separation problem.
4. Greater variation in possible contact time.
5. High ratio of catalyst to reactants.
6. Avoidance of abrasion of catalyst and equipment.
7. Economy in high temperature and high pressure reactions.

These advantages are counter-balanced by certain difficulties, some of which can be eliminated (or at least minimized) by efficient design. Such shortcomings may be:

1. Heat transfer to or from a large fixed bed of catalyst is frequently complicated by the poor thermal conductivity of most catalysts.
2. Difficulties in temperature control.
3. Poor flow distribution can cause over-reaction, under-reaction, or create isolated areas where unwanted reactions predominate.
4. Disintegration or swelling of the catalyst can cause poor temperature and flow distribution control and can bring about deformation of parts of the reactor.
5. Regeneration or replacement of catalyst is usually difficult.
6. Accurate measurement of temperature is generally difficult.

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CATALYSIS

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While many of the difficulties of a fixed-bed operation are eliminated by the use of a continuous system, Bourguet, whose discussion titled "Moving Bed Processes" was based chiefly on the TCC (Thermofor Catalytic Cracking) process, pointed out that many design problems remain. For efficient and economical operation, moving-bed equipment must be designed for:

1. Uniform flow of solids through the reaction vessels.
2. Uniform distribution of reactants through the solids.
3. Circulation of solids with minimum attrition and minimum erosion of equipment.
4. Heat economy through solids circulation, heat exchange, etc.

DESIGN EXPEDIENTS

For the fixed-bed reactor, Stiles went on to outline how some of the shortcomings of the system are overcome. Such methods include:

1. Multiple reactors in parallel or in series to control flow distribution and temperature.
2. Sheath-type reactors with both internal and external heat exchangers for temperature control.
3. Multiple-tray reactors for flexibility. With this type of equipment, flow can be redistributed between trays, reactants can be heated or cooled, additional reactants can be added, product can be withdrawn, a new reactant can be added, and types of catalyst can be varied from tray to tray. This type of reactor can also be designed for easy access to the catalyst either for inspection, redistribution, or change, through side ports or, if desired, arrangements can be made for in-place regeneration.

THE TCC MOVING-BED PROCESS

Major elements of this typical system are:

1. *Catalyst Lift.* The lift system consists of a pot at the base, where catalyst from the regenerator is picked up by gas streams, one or more tapered lift pipes through which the gas-catalyst mixture flows at stream-line velocities, and a separator at the top. The gas lifting medium may be air, or other gases such as flue gas or steam.
2. *Seal Leg.* This is a pipe designed to permit catalyst to flow continuously from the lift separator, which is at atmospheric pressure, into the reactor, which operates at 10 to 15 lb./sq. in.
3. *Reactor System.* The reactor system is designed to provide uniform mixing of incoming catalyst and oil streams, to maintain efficient contact between these two streams through the reaction zone, and to permit vapors to separate from the spent catalyst. Catalyst flows from the reactor to the regenerator through a

number of transfer pipes. Purge steam, introduced just above these pipes, displaces the residual oil vapor from the spent catalyst stream, thus forming a seal between the reactor and the regenerator.

4. *Regenerator System.* The function of the regenerator is to burn off the carbonaceous deposit from the catalyst without damage to the catalyst from excessive heat. The catalyst gravitates uniformly downward through the regenerator while air is forced through the moving bed of catalyst by means of a blower. Some of the heat of combustion is carried by the catalyst to the reactor to partially satisfy the endothermic heat of cracking; some is removed as sensible heat by the fuel gases; excess heat is removed through a cooling coil system which produces much of the steam requirement for the process.

While the moving-bed technique, concluded Bourguet, has been largely applied to petroleum refining, it is finding increasing application in other fields. There are now processes for petroleum coking, lube oil refining, lime burning, shale oil retorting, pyrolytic cracking of light hydrocarbons for ethylene production, and many others.

Operating Problems

Out of his long experience with catalytic processes, Harris (Rohm and Haas), who spoke on "Operating Problems," pointed to several design and operating factors which affect operating economy as well as plant safety.

In the first place, said Harris, operating conditions should be as close as possible to atmospheric temperature and pressure. This is an ideal seldom attained in practice since it is generally in conflict with the basic thermodynamics of the process. However, where their use is possible, lower temperatures and pressures mean minimum cooling-off periods and minimum handling of heavy pieces. Design of equipment for easy assembly and disassembly is also important to save time during catalyst changes. If the catalyst has a tendency to expand and to coke badly, the converter should be designed with a removable catalyst container.

EXPLOSION DANGERS

Operation of catalytic processes at reduced pressures is not common since, with total pressure less than atmospheric, air may be drawn in and explosions may result. The same type of hazard exists when it is necessary to change a pyrophoric catalyst. While the converter is cooling, the contained gases contract and air may again be sucked in with disastrous results.

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CATALYSIS

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CATALYST POISONS

Purity of the feed gases has a marked effect on operating expense, since the impurities may be catalyst poisons causing permanent or temporary catalytic inactivity. If the poisoning is temporary, it may be possible to reactivate the catalyst *in situ*. If the poisoning is permanent, however, the results are more serious. The protection of feeds from accidental contamination is a real and ever-present operating problem in catalytic processing. Contamination of the catalyst with mill scale, grease, pipe dope, etc., is a hazard which is at its peak during the start-up period. There is, pointed out Harris, enough sulfur in an onion sandwich to poison a considerable quantity of hydrogenation catalyst.

There may be a temptation to speed up the kinetics of a catalytic reaction by increasing the operating temperature. This must be guarded against, since excessive temperatures greatly reduce the active life of a catalyst, induce side reactions with undesirable by-products, and may even cause a temperature runaway with destruction of the converter internals.

Catalyst Economics

In most cases, said Reitmeier (Girdler), in his talk "Economics of Catalyst Use," the initial cost of a catalyst is not an important factor in the economics of catalyst use and, in itself, does not affect the cost of the product greatly. Some of the factors, besides the initial purchase cost, which affect the economics of catalyst use are catalyst activity, catalyst life, catalytic poisons, and resale value of spent catalyst.

For example, in many cases, such factors as increased yields, greater selectivity, improved product quality, greater capacity, milder operating conditions, and savings in utilities may be among the advantages of replacing a catalyst at the optimum time. On the other hand, where a catalyst is being used in a system which operates continuously for several months to one or two years with only planned shutdowns for maintenance, it is essential that the catalyst have sufficiently long life with little change in activity. The cost of an unscheduled shutdown, along with the lost production, may amount to several times the value of the catalyst.

IMPORTANCE OF CARRIER

Careful selection of the carrier will

(*Continued on page* 138)

CATALYSIS

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reduce the degree of chemical reaction of the catalytic ingredient with the carrier. It can also reduce the changes that might otherwise occur in pore size and surface area, changes which often influence the activity of the catalyst. The carrier also has an important bearing on the physical ruggedness of the catalyst, that is, on its ability to withstand spalling and breakage.

THE USER'S RESPONSIBILITY

Many of the conditions that influence the life of a catalyst are controllable only by the customer using the catalyst. Full consideration should be given to the catalyst when the plant is being designed and built. In general, the factors that influence the activity, life, and performance of a catalyst can only be partially determined in laboratory and pilot plant work; it requires commercial experience to evaluate performance fully. It is advisable that the user of a catalyst take full advantage of any commercial experience that may be available either from other users or from the supplier.

The Crystal Ball

What is the future for catalytic processes in the chemical industry? According to Thomas (Sun Oil), in a paper "Trends and Prospects" (read by C. G. Kirkbride, Sun Oil), important developments can be anticipated in plastics and rubber, petroleum refining, and, perhaps, nuclear reactions.

One of the most important developments of recent years has been the discovery of "stereo-specific" catalysts, which have the property of polymerizing certain substances in an ordered or "isotactic" manner. Two such systems have been used recently to make synthetic "natural" rubber. One catalyst used is a dispersion of metallic lithium and the other is a "Ziegler" type catalyst, that is, an aluminum alkyl-titanium chloride combination.

It is clear that a whole new frontier of catalytic chemistry has been discovered here. In the immediate future, we can expect to see stereo-oriented polypropylene and polybutene plastics on a commercial scale and synthetic "natural" rubber catalytically produced from catalytic isoprene.

Looking further into the future, one can even see the possibility of synthetic "natural" carbohydrates such as sugar.

TURBINE FUELS

For the past twenty-five years, the

petroleum industry has undergone a revolution as catalytic processes have displaced thermal processes and have provided new tools for the petroleum refiner. However, antiknock quality in gasolines is significant only for piston engines. Should the gas turbine engine turn out to be the power plant for the automobile of tomorrow, one can picture catalytic processes doing the major job of converting crude oil to desirable turbine fuel. This transition will, however, probably be a gradual one, since it is certain that reciprocating engines will not disappear overnight.

CATALYZED NUCLEAR REACTIONS?

The fusion of hydrogen into helium, which normally takes place only at fantastically high excitation energies, has recently been made to take place in liquid hydrogen. A deuteron combined with a mu-meson to form a "molecule." The nuclei then fused to form He^3 with the liberation of energy and the regeneration of the catalyst, a mu-meson. At the present time, this is not a practical catalytic reaction. Yet, it is an important observation and an important concept. Catalysts may well turn out to be the key that will unlock nuclear fusion energy for practical use.

The widespread acceptance for the "New Ideas in Instrumentation Contest" at the Instrument-Automation Conference and Exhibit in New York last year has created high interest in this year's activity to be held in Cleveland, Sept. 9-13. Six awards were made last year, entries are now being received by the Instrument Society of America, sponsors of the entire Conference and Exhibit, for this year's contest. Entries are not limited to ISA members. ☐

The major engineering societies of the U. S. have formed a five-man North American Control Committee on automatic control in industry. The committee was formed to represent the American engineering societies in the organization of the International Control Federation. Members are: Rufus Oldenburger (ASME), chmn.; Joel Hougen (A.I.Ch.E.); H. E. Chestnut (AIEE); John Lozier (IRE); Robt. Jeffries (ISA). ☐

Cleveland is soon to get a $1,525,000 new Engineering and Scientific Center. Exemplifying the growth and importance of engineering in the area, the new structure will provide meeting facilities for more than 53 engineering and technical groups and will be a center of technical education. ☐

A.I.Ch.E.

News of the Field

FROM LOCAL SECTIONS

TRENDS AND GROWTH IN FULLY-AUTOMATIC PROCESS CONTROL

At Southern California Section's March meeting Stanley Dawkins, field engineer, Consolidated Electrodynamics, analyzed trends and developments behind the latest innovations in automation.

Modern process instrumentation is based on simplicity, reliability and quick return of the cost of investment. Chromatography is the "rising star" in the field, according to Dawkins. It presents a rapidly changing picture, depending upon the discovery of new column materials and sensing devices.

Many of the newer chemical processes require precise production control, a fact which may be critical in their utilization. For example, catalytic reactions need high feedstream purity, and to obtain the degree necessary, control must be held within rigid limits.

To meet today's competition, Dawkins has found that plant control with complete feedback instrumentation is often considered in the design of new plants. (A result of this modern instrumentation and control, Dawkins showed, is the gradual disappearance of surge capacity between each subsection of new plants.)

Since straight-through-feed plants require immediate analysis for prompt feedback, instrument manufacturers have developed in-plant instrumentation for on-stream analysis. These are non-versatile instruments designed for the particular stream on which they are used and are less expensive than versatile research instruments.

A typical application for process instrumentation, Dawkins explained, is a refinery's problem of disposing of sulfur, which, if not recovered, would go into the atmosphere as H_2S or SO_2. In the recovery process discussed by Dawkins, which is based on the following reactions,

$$H_2S + 1\tfrac{1}{2}O_2 \rightarrow H_2O + SO_2$$
$$2H_2S + SO_2 \rightarrow 3S + 2H_2O$$

stoichiometric proportions of hydrogen sulfide and sulfur dioxide are obviously necessary if one or the other is not to go up the stack with a resultant loss of sulfur. A mass spectrograph at the outlet of the system immediately feeds back information used to regulate the air supply which controls the proportions of these materials.

—*R. D. Shecline*

At Philadelphia-Wilmington Section (*L. R. Bechtel*) one-day meeting in Philadelphia, Zeisberg Award presentation is made to Anton Roeger, III, of Lehigh University, by J. B. Marker, right. (See p. 130 for full report on this important meeting.)

STUDENT ENGINEERS PRESENT TECHNICAL PAPERS

Southeastern Regional Student Chapters Conference, held in March, and the February meeting of the Maryland Section both focus the attention of chemical engineers on the work of the students.

Keynote speech at the **Southeastern Student Conference** (*F. N. Peebles*) was given by H. A. Curtis, director of T.V.A. His subject, presented to the 190 attending student engineers from 12 colleges and universities, was "Fifty Years of Chemical Engineering." Technical papers were presented on the subject of the nuclear reactor by experts from Oak Ridge. The students toured ORNL, including visits to the graphite pile, the swimming pool reactor facility, the megacurie radioactive isotopes handling facility, and the unit operations section.

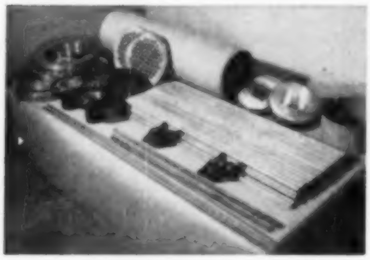
Eleven students presented their own papers, with first prize going to J. L. Ballard and K. S. Burns, Univ. of Tenn., for "The Effect of Solute Dispersion on Turbulence in the Dispersed Phase of Liquid-Liquid Extraction Systems." Second prize was won by D. V. Knight and R. W.

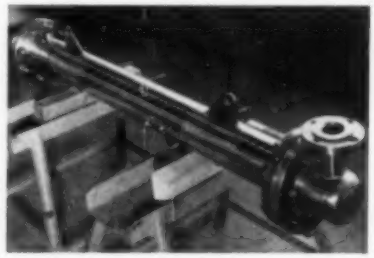
(*Continued on page* 142)

Corrosioneering News

Quick facts about the services and equipment available to help you reduce corrosion and processing costs.

Published by The Pfaudler Co., Rochester, N.Y., U.S.A.





From stock parts... to finished heat exchanger... to you without the time consuming delay of "custom design."

Pfaudler stockpiles a complete line of flexible-standard components which can be assembled to fill your needs in *two to six weeks.*

Two-week delivery possible

If your process requirements can be met by either a single- or double-pass carbon shell heat exchanger in the capacity range between 56 to 316 sq. ft., you can get "off-the-shelf" delivery in *just two weeks.* Other standard sizes up to 20" shell diameter are quickly assembled to your specifications in just *four to six weeks.*

Tally these added advantages to your profit when you order Pfaudler heat exchangers:

They're versatile. Use them as heaters, condensers, or coolers. These units are designed to ASME and TEMA codes for 75 psi tube pressure and 150 psi shell side pressure up to 350° F. Only slight modifications are required for higher pressures and an expansion diaphragm can be added to meet higher temperature gradients.

They're economical. Due to standardization of design and the pre-stocking of components, they cost much less than custom built units.

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Pfaudler engineers are always ready to help you with your heat exchanger problems.

You'll also find a copy of Manual 837, "Pfaudler Heat Exchangers and Condensers," helpful. Along with complete descriptions of Pfaudler heat exchangers and condensers, it contains useful performance and thermal design data. Write for a copy today.

New glassed pump fights off corrosion for years. A new Goulds' centrifugal pump with Pfaudler glassed interior surfaces assures years of corrosion-free operation at low cost.

Resists *all* common acids except hydrofluoric to at least 212°F. and alkaline solutions up to pH 12 at 212°F.

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How to take the guesswork out of buying columns

It's no easy matter to select the proper columns for a given operation.

You have to balance such diverse factors as cost, corrosion resistance, handling and cleaning, vapor and liquid capacity, pressure drop, load efficiency, etc., etc., etc.

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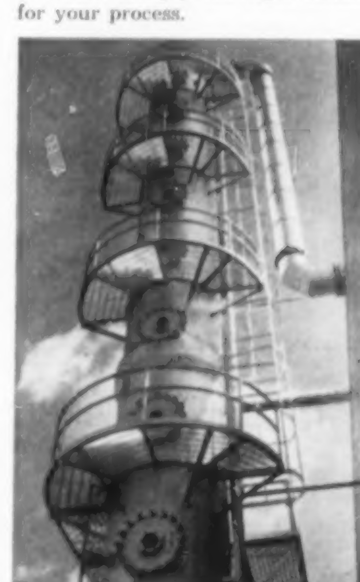
To begin with you can find the answers to many basic questions in our Bulletin No. 940. Write for a copy.

Then you can check with Pfaudler for detailed answers to your specific problems.

Result? Simply the right column for your process.



News of the Field
FROM LOCAL SECTIONS

(*Continued from page 140*)

A. R. (Dick) Moisson, Clemson College chemical engineering junior (right), is Southeastern Student Section's new president, is congratulated here by C. E. Littlejohn, head of Clemson's chemical engineering dept.

Bondurant of North Carolina State College, and honorable mention went to C. L. Sibley of the Univ. of Florida.

At **Maryland Section's** (*P. Messina*) February meeting four student chemical engineers from local schools presented brief technical papers to the assembled engineers. In the audience to hear the honored students were F. J. Van Antwerpen, national A.I.Ch.E. secretary, and J. Henry, asst. national secretary. The four students were E. Adams of the Univ. of Maryland; J. Anderson of Johns Hopkins; R. Marsheck of Maryland; and C. Coffman of Johns Hopkins.

Before the evening meeting where the local students were heard, Van Antwerpen, Henry and the local Maryland Section officials were hard at work planning the National meeting to be held in Baltimore in September, 1957.

SOLVENT EXTRACTION PROCESS FOR URANIUM SAID TO BE CHEAPER

Presenting process details for an anion resin-exchange process and a solvent extraction process, both for recovering uranium from sulfuric acid leach liquor, R. S. Long, project leader of Dow Chemical's Western Division Atomic Energy Group told the March meeting of the **Northern California Section** that the alkyl phosphate solvent extraction process is cheaper except where undesirable materials in the ore cause stable emulsions.

Both processes will become increasingly important as high grade ores are depleted. Costs of both processes are expected to reach about $8 per pound of 80% U_3O_8 as compared to the present cost of about $15 a pound. In cases where stable emulsions are formed, the higher-capital ion exchange process can be justified.

—*J. C. Ornea*

ONE-DAY MEETINGS, COMPUTERS, TECHNICAL SUBJECTS, FEATURE LOCAL MEETINGS

Although nitric acid does not rank in tonnage with such chemicals as sulfuric acid, it is commercially one of the most important inorganic chemicals produced. To prove this to the January meeting of the **Central Ohio Section** (*W. W. Ellis*), E. A. Ross, assistant chief engineer of Chemical and Industrial Corp., Cincinnati, stated that in 1935 only 96,000 tons of nitric were produced, while in 1955 production was 2,200,000 tons. Almost all nitric produced went at one time into explosives, but today 75% goes into fertilizers, 13% into various chemical processes, and only 12% into explosives. In the United States the pressure, and combination oxidation pressure, processes are mainly used, but in Europe the atmospheric oxidation process is still in use to a great extent.

The joint one-day Fourth Annual

N. S. Banta, chairman of Sabine Area Section, addresses morning session of meeting.

Technical Meeting of the **Sabine Area Section** (*P. H. Richer*), held with local ACS section, featured, among a full program, the problem of industrial water supply which is a vital subject in this water-short area. H. F. Smith's paper on Experimental Designs and Skarstrom's paper on Gas Chromatography also attracted high interest at the one-day session.

Computers Hold Floor

The medium-speed computer has become a highly useful tool for the chemical engineer in the petroleum and chemical industries. Proving this, a panel of J. S. Bonner, Bonner & Moore Engineering Associates; M. R. Tek, leader of the fluid mechanics group, mathematical engineering branch in the research and development department of Phillips Petroleum Co.; G. W. Tracy, group leader in the research dept. of Pan American Petroleum Corp.; and Paul Fullerton, Southwestern Computing Service, moderator; was held at the March meeting of the **Tulsa Section.**

Bonner, who won the "best paper" award at the Pittsburgh national meeting of A.I.Ch.E. last September with a paper on plate-to-plate machine computations, emphasized that there is more work to be done to make computer applications effective in the fields of refinery and chemical plant process problems. A single unit, such as a catalytic cracker, can be optimized now, but optimization of a complete refinery is still some distance away.

Phillips Petroleum's computing center, Tek explained, handles many applications of computers to the company's operating problems such as working with mass spectrometer data teletyped from the Borger, Tex., refinery and chemical plants. Calcula-

(*Continued on page* 144)

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tion of the production of the company's gas wells is another application.

For the chemical engineer Fullerton listed some of the applications of computers in petroleum production work the chemical engineer should be interested in: reservoir behavior computations on phase solution drive; water drive and simplified gravity drainage type reservoirs; predicting performance of water floods; estimation of reserves; seismic and gravity meter surveys in exploration work; and adiabatic and isothermal flash calculations for field separators.

Taking up a similar subject, E. H. Gray, Phillips Petroleum, explained Electronic Computers and their Application to Chemical Engineering Problems to the February meeting of the **Texas Panhandle Section** (*C. M. Oktay*).

The South—Industrial Expansion

The remarkable industrial expansion of the south since World War II, particularly in the chemical industry, has rapidly raised the south's need for chemical engineers, and has created a serious supply problem, J. C. Patchen, Patchen and Zimmerman Engineers, told the March meeting of the **Savannah River Section** (*R. O. Pekkala*). The present needs of the south far surpass the production of engineers by southern universities. The distant needs for engineers will probably be in the vicinity of 36,000 a year. Patchen has a four point formula to solve this problem: 1) Sub-professional personnel must be rigorously trained to ease the burden of graduate level personnel; 2) Existing school systems should be expanded and drilled to produce more technical personnel through post-graduate level. The graduated technical personnel are to be trained to assume greater responsibility than at present; 3) mechanical and electronic computing aids should be used to eliminate waste of engineering manhours; 4) better utilization of engineering manpower should be realized.

At the March meeting of the **Atlanta Section** (*L. Hutzler, III*) National A.I.Ch.E. director C. A. Stokes talked on local section and national Institute affairs. Of particular interest to local members were the figures on Institute membership, finances, and publications. Stokes and the members discussed the problems of professionalism at some length and Stokes explained the official

Institute position on professional registration.

Also Meeting

In January the **Pittsburgh Section** (*G. Karnofsky*) listened to L. A. Shattuck, Jr., Univ. of Pittsburgh, tell about The Selection of Growth Securities in a Period of Inflation. Shattuck presented the ground rules for investment and then gave specific stock recommendations to illustrate his points. . . "Higher Education is Not a Luxury but a Means of Survival." This was the subject of T. A. Wilker, superintendent of Carbide and Carbon Chemical's Texas City plant, speaking to the January meeting of the **South Texas Section** (*E. E. Ludwig*). Wilker emphasized the need for increased support of public educational institutions by the public and by industry. Private educational institutions can also use aid from industry and should get it. . . At **Savannah River Section's** (*W. D. Sandberg*) January meeting, W. P. Overbeck, DuPont's Savannah River plant, spoke on recent developments in the fields of astronomy and cosmology and showed studies from the Mt. Palomar 200-inch telescope. . . A "Reactor For Rhode Island" held the floor at February Meeting of the **Rhode Island Section** (*J. L. Campanella*). A. L. Quirk, chairman of the Rhode Island Atomic Energy Commission, explained the theory of nuclear reaction and power, and told the engineers that he believed a nuclear reactor would promote the electronic industry in Rhode Island. He proposed that the state build a one megawatt reactor for research in all fields. . . **Akron Section** (*E. W. Campbell*) heard a discussion of the so-called "octane race" led by H. W. Grote, Universal Oil Products. The demand for higher and higher octane gasoline, Grote said, has forced the octane number up at a constant rate and presented the petroleum industry with the problem of keeping its "upgrading" processes constantly improving. . . February at the **Ichthyologists (Boston Section)** (*A. S. Collins*) saw the engineers turning to the problem of Community Planning. Leading the way was speaker Allen Benjamin, planning engineer and consultant, who acclaimed the progress that has been made in applying general principals and objective thought in a field previously dominated by politics and selfish interests. Benjamin went on to discuss some of the more important problems of community planning, including the control of industry, types of residences, zoning provisions,

(*Continued on page* 147)

CANDIDATES FOR MEMBERSHIP IN A. I. Ch. E.

The following is a list of candidates for the designated grades of membership in A.I.Ch.E. recommended for election by the Committee on Admissions.

These names are listed in accordance with Article III, Section 8 of the Constitution of A.I.Ch.E.

Objections to the election of any of these candidates from Members and Associate Members will receive careful consideration if received before June 15, 1957, at the office of the Secretary, A.I.Ch.E., 25 West 45th Street, New York 36, N. Y.

Member

Ambrose, Everett J., *Wilbraham, Mass.*
Barnett, James C., *Kirkwood, Mo.*
Barton, James, *Rochester, N. Y.*
Bugel, Robert H., *Wilmington, Del.*
Dabic, Steve, *Oak Ridge, Tenn.*
Dolan, Earl V., *Oakland, Calif.*
Eckhaus, Sigmund R., *Baltimore, Md.*
Fair, W. H., III, *Corpus Christi, Tex.*
Frank, Wallace S., *Waterford, N. Y.*
Gander, Frederick W., *Buffalo, N. Y.*
Gibbs, Orlin J., *Port Arthur, Tex.*
Gilkeson, Murray Mack, Jr., *New Orleans, La.*
Goldbeck, Martin, Jr., *Orange, Tex.*
Grady, Lester D., *Palmerton, Pa.*
Gromatzky, Erwin A., *New Orleans, La.*
Hanisian, John, *New York, N. Y.*
Hartman, George S., *Roslyn, Pa.*
Hayworth, Curtis B., *Morristown, N. J.*
Hor, Everett, *Great Notch, N. J.*
Hoyt, Fred W., *Rochester, N. Y.*
Hyde, John P., *Jersey City, N. J.*
Joyce, Thomas P., Jr., *Pittsburgh, Pa.*
Jonke, Albert A., *Elmhurst, Ill.*
Kerry, Frank George, *New York, N. Y.*
Kuhlman, William D., *Midland, Mich.*
Malcolm, James Edwin, *Arlington, W. Va.*
Morbeck, Robert C., *Westfield, N. J.*
Myers, Noel W., *Decatur, Ill.*
Naczi, Joseph J., *Wilmington, Del.*
Nugent, Robert P., *Chillicothe, Ohio*
Oxford, C. W., *Fayetteville, Ark.*
Page, Edward C., Jr., *Bryn Mawr, Pa.*
Parker, Lee Allen, *Upper Montclair, N. J.*
Peck, Albert C., *Walnut Creek, Calif.*
Porada, John, *Bayonne, N. J.*
Reid, Toy F., *Kingsport, Tenn.*
Rhodes, Harrison B., *Paramus, N. J.*
Ries, Harold C., *Emeryville, Calif.*
Rubin, Martin J., *Long Island City, N. Y.*
Seguin, Vernon C., *So. Charleston, W. Va.*
Seifarth, John H., *Wilmington, Del.*
Sergeys, F. J., *Baton Rouge, La.*
Smith, William J., *Delaware City, Del.*
Stevens, James I., *Idaho Falls, Idaho*
Struck, Robert T., *Library, Pa.*
Sullivan, Roger L., *Tonawanda, N. Y.*
Sutter, Robert C., *Painesville, Ohio*
Swaim, C. Donald, Jr., *San Marino, Calif.*
Ulrich, George W., *Managua, Nicaragua*
Willard, Gradon F., *Callery, Pa.*
Williams, W. D., *Toledo, Ohio*
Winson, Martin J., *Plainfield, N. J.*
Woods, George E., *Wilmington, Del.*
Yacoe, J. Craig, *Wilmington, Del.*
Young, Elias H., *Fair Lawn, N. J.*
Zabban, Walter, *Pittsburgh, Pa.*
Zahn, Roth G., *So. Charleston, W. Va.*

Associate Member

Akhavein, M. M., *Brookline, Mass.*
Alcalde, Antonio, *San Francisco, Calif.*
Baldwin, Chales R., *Frederick, Md.*
Beasley, Neil, *Texas City, Texas*
Beverly, John A., *Rochester, N. Y.*
Brown, Rene P., *Big Spring, Texas*
Callahan, Matthew F., *Pittsburgh, Pa.*
Clinard, Outten J., Jr., *Irvington, N. J.*
Donnelly, Edmund H., *E. Hartford, Conn.*
Duris, Edward P., *No. Braddock, Pa.*
Engel, J. Richard, *Oak Ridge, Tenn.*
Fischer, Clifford O., *Cincinnati, Ohio*
Flinn, Richard A., *Verona, Pa.*
Goldman, Arthur J., *Bronx, N. Y.*
Gorry, Matthew, *Albuquerque, N. M.*
Greening, Alvin R., *Wilmington, Del.*
Gusler, Jack S., *Dallas, Texas*
Hackman, E. Ellsworth, *Philadelphia, Pa.*
Hardy, John F., *Pampa, Tex.*
Harris, Morley M., *Pittsburgh, Pa.*
Homiak, Michael, *Bound Brook, N. J.*
Howe, H. Gordon, *Westfield, N. J.*
Johnson, Charles A., *Pittsburgh, Pa.*
Johnston, Dean A., *Evans City, Pa.*
Kiser, Kenneth M., *Schenectady, N. Y.*
Kurtz, Phillip I., *Glenshaw, Pa.*
Kwolek, Stanley J., *Pittsburgh, Pa.*
Lowe, Byron R., *Salt Lake City, Utah*
McCoy, Bernard A., *Reading, Pa.*
Mosher, Paul R., *Indian Head, Md.*
Moss, John, *Niagara Falls, N. Y.*
Nash, John M., *Bristol, Conn.*

News of the Field

FROM LOCAL SECTIONS

(*Continued from page* 145)

and other regulations. . . **El Dorado Section** (*A. A. Feerick*) held its February meeting on the subject of The Growth of Chemical Proof Construction in the United States. Speaker was Earl Erich, Tube Turn Plastics, Louisville, Ky.

Report on Indonesia

At the **Southern California Section** (*R. D. Sheeline*) meeting in February, the subject went far afield to the industrial problems of Indonesia. T. E. Hicks, professor of chemical engineering, UCLA, just returned from a year at Gadjah Mada University in Djogjakarta, Indonesia, where he helped develop the new Engineering School, reported on his experiences to the section. Industrial advance is going to be slow and difficult. In spite of one of the densest populations in the world, communication is difficult. There are no newspapers and no public auditoriums. Public health is a major problem, life expectancy is relatively short, and the best approach now will probably be to find industries combining agriculture and industry such as refining sugar.

CANDIDATES

(*Continued*)

Norman, Alden L., Jr., *Boston, Mass.*
Nowrey, Joseph E., *Wilmington, Del.*
Noyes, James P., *Rahway, N. J.*
Nusim, Stanley, *Bronx, N. Y.*
Oakes, Willis R., *No. Madison, Ohio*
Ortloff, Gerald D., *Tulsa, Okla.*
Otto, Robert E., *Wright-Patterson AFB, Ohio*
Pier, Arthur F., *Webster Groves, Mo.*
Pozos, Manuel Alfonso, *Midland, Mich.*
Rotterman, Oscar S., Jr., *St. Louis, Mo.*
Rayford, Richard E., *Schererville, Ind.*
Rinehart, Verne R., *Jackson, Ohio*
Romano, John E., *Wilmington, Del.*
Russo, Anthony, *Cohoes, N. Y.*
Seeba, F. J., *Lake Charles, La.*
Sheehy, Thomas M., *Westend, Calif.*
Siev, Robert, *So. Pasadena, Calif.*
Stephens, Roy C., *Kingsport, Tenn.*
Stine, Richard K., *Northampton, Pa.*
Turner, George C., Jr., *Wilmington, Del.*
Uhler, Clayton J., *So. Charleston, W. Va.*
Vayda, Adam V., *Pittsburgh, Pa.*
Webb, T. Harold, *Texas City, Tex.*
Weiss, Rudolph J., *Pittsburgh, Pa.*
Wemple, Richard E., *Rochester, N. Y.*
Wendel, Martin M., *New Castle, Del.*
Wilson, William J., *Brentwood, Mo.*
Wooten, Lionel E., *Kingsport, Tenn.*
Young, James J., *Newark, Ohio*

Affiliate

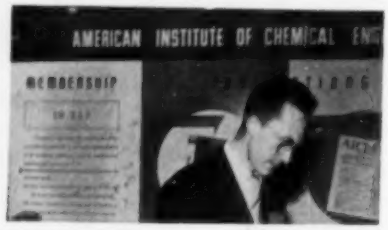
Peightal, T. D. *Pittsburg, Calif.*
Whitcomb, Gordon P., *New York, N. Y.*

CEP CAMERA

EGYPT (AEC of Egypt, U. of Alexandria) Interviewed at Aerojet reactor, N. Abou-Taleb found power generation information useful.

COMPANIES FROM ABROAD AT ATOMIC EXPOSITION

NORWAY (Inst. for Atomenergi) E. Jensen tells CEP roving reporter his interest centers on nuclear ship propulsion. He studied Ford Instrument exhibit.



FRANCE (Ste. des Forges) Giant steel combine is deep in nuclear work. Its representative, J. Doumerc, had main interest in reactor materials, fuels, new metals for reactor technology.

PUERTO RICO's C. R. Garrett gave attention to Aerojet reactor, Leeds & Northrup simulated reactor.

At the recent Atomic Exposition in Philadelphia, *CEP's* roving reporter buttonholed some of the 90-odd visiting engineers and scientists from 15 countries who came to Philadelphia. As they passed through the Exposition, *CEP* interviewed them, found their interests concentrated largely on practical industrial projects. General viewpoint of visitors: they wanted practical information on equipment, materials and methods that can be used *now!*

Typical of the comments was that of Finland's Jafs. "Most important to us is equipment and instrumentation. We import most of it from the U. S. At this exhibit we can compare new American instrumentation with that available in other countries."

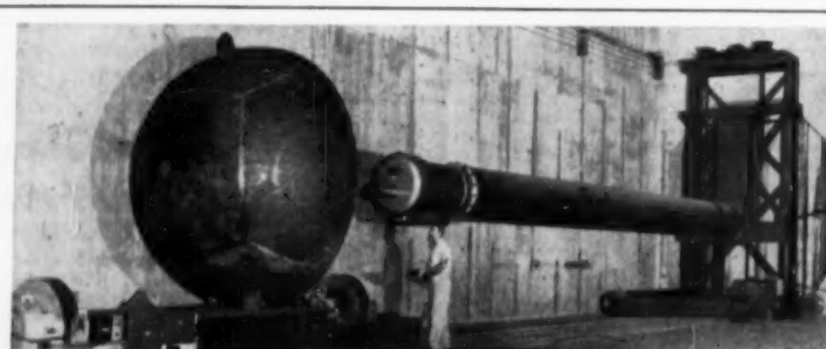
Major interest of the visitors seemed to be centered on instrumentation and power reactor materials (fuel elements, ceramics, etc.). Actual equipment ready to be put into use now was emphasized by most of the visitors as the main feature of the Exposition. Many had come with the intention of actually purchasing equipment for their companies.

ITALY (Elettro Nucleare, Montecatini, Edisonvolta) Emphasizing Italy's need to get started in nuclear industry, their own assignments to purchase for companies, G. Zorzoli, G. D'Arminio-Monoforte, and P. Simonini (l. to r.) were most impressed by the fact that Exposition showed what is available NOW, also by scope of exhibits.

ECUADOR's A. A. Freire held that best feature of Exposition was its inclusiveness and practical use-potential.

SWITZERLAND (Sulzer Bros., Ltd.) This major Swiss heavy equipment manufacturer (pumps, compressors, process steam boilers) is working on a reactor, its representatives W. A. Helbling (r.) and R. Herold showed special interest in fuel element fabrication, metallurgy.

ONE MILLION VOLT X-ray machine at Birmingham, Alabama plant of Chicago Bridge & Iron Co., process vessel fabricator, is shown ready to inspect a pressure vessel head fabricated by the company. Equipment is also used for inspection of welded shell seams in heavy wall pressure vessels. Mounted on rails, the instrument is fixed on the end of a 43-foot long counterweighted boom.



INTRODUCING . . .
MEMBERS OF THE "23-AND-OVER" CLUB!

E. Madison Jones

A. S. West

E. M. Glazier

A professional society's growth depends on many factors. One of these is the hard work on the part of a few dedicated individuals who make it their job to go out and beat the bushes for new members. Acting as catalysts, salesmen, and team managers, these active men have a single purpose in mind—to get their application blanks filled out and signed. The five chemical engineers pictured here were the most successful in the task of bringing in new A.I.Ch.E. members during the year 1956, and are thereby winners in the annual membership application contest.

CEP proudly designates them members of the "23-and-over" Club for leading the efforts of their sections in getting, in the case of the 1956 contest, 23 or more applications for national membership. Their actual records: Jones (*S. Texas*)—64; West (*Philadelphia-Wilmington*)—60; Glazier (*Pittsburgh*)—38; Pritz (*Chicago*)—26; Kaemmerer (*Charleston*)—23.

As members of John McKetta's Membership Committee, these five chemical engineers have told *CEP* the secrets of their success. Says Glazier, "Anyone seeking to obtain new members for the Institute has a two-fold job. He must sell the non-members on joining . . . and he has to sell the present members on helping by providing names of the non-members."

Jones divided his section area into five regions, put a subchairman in charge of each, and had him go out and get at least one engineer in every plant in his region who could personally contact all qualified potential members.

West secured a representative at every company location in his section area—62 in all! Kaemmerer recruited a chairman for each plant, had him appoint contact men who did the actual talking to prospective members.

Glazier and Pritz worked through more centralized committee operations, had their section members furnish names of prospective new members and then had their committee workers personally contact every potential applicant.

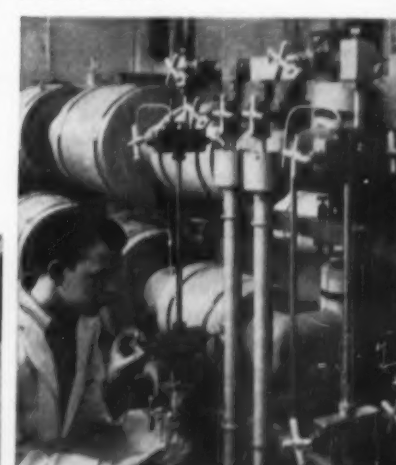
Whatever methods they used, the five "23-and-over" Club members did a lot of work in their "catalytic" role and have earned a well-deserved recognition.

R. E. Pritz

J. F. Kaemmerer

A.I.Ch.E. COUNCIL IN RECENT GREENBRIER SESSION. Partial view, l. to r.: Othmer, Rushton, Van Antwerpen, Sheerin, McAfee, and Chiswell.

THIS WESTINGHOUSE TEST LOOP for study of the corrosive effects of hot, pressurized fluids on the structural materials in nuclear power plants will be devoted to developing and testing corrosion inhibitors, corrosion resistant alloys and corrosion resistant joints in structural materials.



AT RECENT PROCESS CONTROL DINNER held at Northwestern U. in connection with 3-day meeting co-sponsored by A.S.M.E.'s Instruments and Regulators Div. and A.I.Ch.E.'s Process Control Section, Program Committee. Left, (l. to r.): Dave Boyd (UOP), section chmn.; A.I.Ch.E. President J. Henry Rushton (Purdue), principal speaker; and Page Buckley (du Pont), section vice-chmn. Also at Process Control meeting (right), A.I.Ch.E. authors (l. to r.) O. J. M. Smith (U. of Calif.); Neal Amundson (U. of Minn.); Page Buckley.

people


Feldmann

Walther H. Feldmann has been elected president of Worthington Corp. Feldmann has been associated with Worthington since 1944.

New production manager of the separator division of Southwestern Engineering Co. will be **Robert D. Patterson.**

Pittsburgh Coke & Chemical Co. announces appointment of **Colin C. Whyte** to position of chief design engineer of their Chemical Group.


Taft, Jr.

William K. Taft, Jr., rejoins B. F. Goodrich Chemical after two years of military service. Taft will be a technical man at the company's Akron experimental station.

Director of research for Delavan Manufacturing Co., West Des Moines, Iowa, to be **Roger W. Tate.**


Orr

Celanese Corp. of America announces appointment of **William P. Orr** as assistant manager of their Plastics Division. Orr was previously manager of the Celanese Fortiflex polyolefin plant in Houston, Texas, where he will be succeeded by **Burton E. Cash.**


Cash

The Distinguished Faculty Lecture of the Year for the Illinois Tech chapter of Sigma Xi was given by **Robert C. Kintner,** professor of chemical engineering at Illinois Institute of Technology. His subject: "Bubble and Drop Phenomena."


Rose

Esso Standard Oil Co. names **Harold J. Rose** as assistant general manager of the company's Chemical Products Department.

Ian C. MacGugan promoted to manager of paper and pulp research and development at Becco Chemical Division, Food Machinery and Chemical Corp., Buffalo, N. Y.

New managerial appointments in Pennsalt Chemicals Industrial Division include: **Leslie A. Gillette** as manager of the Technical Department; **Dwight L. Miller** as chief chemist; **Otto T. Aepli** to head the Analytical Section; and **George P. Martin** to be supervisor of Development Engineering.


Stephens

Claude O. Stephens elected president of Texas Gulf Sulphur Co. Stephens has been associated with Texas Gulf since 1932.

Clarence W. Shonnard joins staff of Tonawanda, N. Y., laboratories of the Silicones Division, Union Carbide and Carbon.

D. H. Killeffer receives the first James T. Grady Medal, given by the American Chemical Society for distinguished reporting of chemical progress.

Joseph A. McDonough recently joined the process development staff of the Research and Development Department of the Procter & Gamble Co. **E. O. Korpi** has been named manager of manufacturing and product development of P&G's Food Products Division.


Miller

John J. Miller appointed general manager of the Alumina Division of Olin Revere Metals Corp. Before joining Olin Revere, Miller was assistant chief engineer in charge of chemical engineering for the Aluminum Co. of America.

Promotions at Monsanto Chemical Co. include: **Charles A. Magarian** to group leader of the industrial resins group, Research Department, Plastics Division, Springfield, Mass.; **W. E. Weiner** to assistant director, Central Research Department, Research and Engineering Division, Dayton, Ohio; **J. R. Fair,** to section leader, Central Research Department, Research and Engineering Division, Dayton, Ohio; and **R. E. Lenz** to assistant director, Engineering Department, Research and Engineering Division, St. Louis.

Raymond Stevens, president of Arthur D. Little, Inc., has been named as one of two men to head the Gordon Research Conferences this year. Also named was **Robert W. Schiessler** of Socony Mobil Laboratories, Paulsboro, N. J.


Nielsen

New president of Babcock & Wilcox is **M. Nielsen,** for the past two years executive vice-president of the company. Nielsen joined Babcock & Wilcox in 1924.

Edward G. Fochtman named supervisor of chemical engineering research at Armour Research Foundation of Illinois Institute of Technology, Chicago. Fochtman is a specialist in atmospheric pollution and other fine particles research.

Paul L. Raymond, project manager in the Research Division of National Research Corp., gives paper on "Molybdenum Plating Inside of Large Bore Tubes" at Washington, D. C. meeting of the Electrochemical Society.

Chemstrand Corp. elects **Carl O. Hoyer** as vice president, engineering. Hoyer will continue as director of engineering.


Hoyer

Appointments at Acheson Dispersed Pigments Co. include: **Harry E. Knox, Jr.,** as general works manager in charge of plants in Philadelphia, Orange, Texas, and Xenia, Ohio; **Howard Acheson, Jr.,** as works manager of the Philadelphia plant; and **Dario Passigli** as group leader of the Process Research Group in the Research and Development Department.

Harry D. Robbins has been transferred from Union Carbide Nuclear Co. at Oak Ridge to the Tonawanda, N. Y., Laboratories of Linde Air Products Co., another division of Union Carbide.

United States Rubber Co. names **George R. Vila** vice-president. Vila will also be general manager of the company's Naugatuck Chemical Division.

Robert W. Krebs appointed by Esso Research and Engineering as director of the Chemicals Research Division. Krebs was formerly associate director of the Esso Research Laboratories in Baton Rouge, La.


Krebs

Promotion of **Harvey L. Anderson** to applied research section leader, Central Research Department, has been announced by Minnesota Mining & Manufacturing Co.

(Continued on page 152)

people

Harvey M. Merker honored with title "First Citizen of Detroit" by the Detroit Common Council. Merker, associated for more than 45 years with Parke, Davis & Co., has long been active in the affairs of the A.I.Ch.E.

Gloskey

Carl R. Gloskey named by Metal & Thermit Corp. as manager of their Process Development Division.

Edward A. Mason has resigned his position as director of research at Ionics, Inc., to accept appointment as Associate Professor of Nuclear Engineering at the Massachusetts Institute of Technology.

New manager of production and engineering for the Silicones Division, Union Carbide and Carbon Corp., is **R. S. Abrams.**

Wingard

Davidson-Kennedy Associates Co. announces that **Milton Wingard** has been appointed vice president-technical director and simultaneously elected to the Board of Directors. Prior to joining Davidson-Kennedy in January, Wingard was project engineer, Chemical Plants Division, Blaw-Knox Co.

George F. Kirby, Jr., has been elected a director of Ethyl Corp. Kirby is vice-president in charge of research and development and has been associated with Ethyl Corp. since 1940. Also at Ethyl, **Theodore J. Carron** has been appointed assistant director of administration and services at Ethyl's Research and Development Laboratories in Detroit.

King

Armour and Co. names **John A. King** as director of research. King has specialized in industrial research in the chemical and pharmaceutical fields.

Continental Oil Co., Houston, Texas, announces two promotions. **A. L. Anderson** will be research group leader, service section, and **Irwin Politziner** will be research chemical engineer, process laboratory.

(*More People on page* 154)

the chemical engineer in

MARKETING

McFarlane

Alexander N. McFarlane, vice-president and general sales manager of Corn Products Refining Co., elected president of Corn Products Sales Co. McFarlane has been associated with Corn Products Refining since 1934.

Fred K. Shankweiler assumes position as director of sales of the Cellulose Products Department of Hercules Powder Co.

Two new sales appointments at Archer-Daniels-Midland Co. are **George P. Woodward** as manager of the Philadelphia district sales office, and **William A. Weiss** as technical sales representative in the Industrial Cereal Products Department.

Alfred E. Mohan joins the Milton Roy Co., Philadelphia, as member of the sales-engineering staff.

Christopher P. Blakeley appointed chemical products engineer in the Boiler Sales Department of Hagan Chemicals & Controls, Inc., Pittsburgh.

Director of sales in newly-created Resin Products Department of Celanese Corp. of America's Plastics Division will be **Charles W. Proudfit.**

David A. Edwards named plastics technical sales representative in Akron, Ohio, area for Naugatuck Chemical Division, United States Rubber Co.

B. F. Goodrich Chemical Co. appoints **Harry J. Glutting** as Geon sales representative.

Gerald J. Bayern, recently senior market analyst for Allied Chemical and Dye's Barrett Division in New York, becomes manager of market research for W. R. Grace's Research and Development Division.

Howard H. Elliott, Jr., is new member of the sales staff of Norwood Controls. Elliott was previously associated with the Westinghouse Atomic Power Division and with the Chemical Plants Division of Blaw-Knox.

William L. Root, 3rd, has joined the Bethlehem Foundry and Machine Co. and will represent them for chemical process equipment sales. Root was formerly a sales engineer with Simplex Valve and Meter Co.

Appointment is announced of **J. L. Galt** as West Coast marketing manager for General Electric's Chemical Materials Department.

Babbitt

John F. Babbitt, formerly with the Gas Process Division of the Girdler Co., appointed sales engineer in New York office of Chemical Construction Corp.

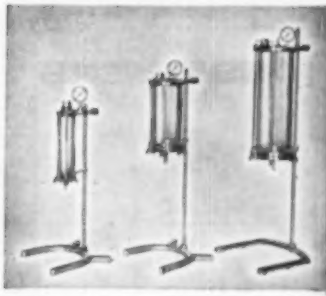
Necrology

Frank Skrek, 44, district head, Merck & Co., Danville, Pa.

Charles L. Campbell, 68, retired, formerly associated with E. B. Badger & Sons Co.

Kent R. Fox, 70, manager, sales development, Organic Chemicals Division, Monsanto Chemical Co.

Charles F. Boschen, 41, chemical supervisor, E. I. Du Pont, Deepwater, N. J.



Illustrated above, left to right: Model 9; Model 10; Model 21 and 21-1.

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- Accomodates Standard Ertel Asbestos Filter Sheets as well as any other type filter media

MODEL	CAPACITY Cu Cm	CAPACITY Ounces	SHEET Dia	AREA Sq In
21-1	3750	130	9½"	21
21	[illegible]	96	9½"	21
10	[illegible]	65	[illegible]	9.63
9	[illegible]	9	[illegible]	0.54

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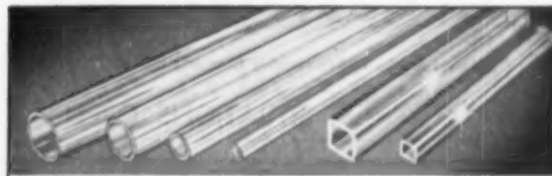

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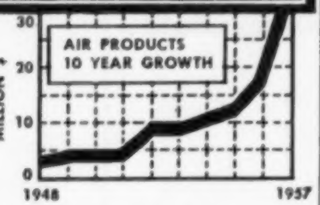

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- FIELD OPERATIONS MANAGER
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- MANUFACTURING & PROCESS ENGINEER
- SALES ENGINEERS

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WHAT major organization offers continual original work assignments?

For the answer, turn to page 12.

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Work consists of translating process requirements into completed operating pilot plants and includes mechanical design, proper application of equipment, instrumentation, cost estimation, scheduling, materials procurement, field supervision of construction, initial operating shake-down, and new equipment development.

Experience in any of the above fields is desired with the ability to direct the work of others and to deal with a professional research staff. Excellent opportunities for advancement. Salary commensurate with training and experience.

Give full details of education, experience, desired salary, availability date and references. All inquiries will be considered promptly and held confidential.

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PROCESS EQUIPMENT ENGINEER—Heavy Chemicals. Age 36. Desire position in Cleveland area. Can handle design, sales, installation and operation of most types of equipment. Fully qualified, excellent record, available soon. Box 7-5.

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PROJECT ENGINEER—B.S.Ch.E. 1949, age 30. Strong background design and project administration, organic, inorganic, and AEC plant projects. Some production supervision and development experience. Desire responsible project engineering position offering growth potential. Box 6-5.

(*Continued on page* 161)

FACULTY POSITION in Chemical Engineering—September 1957. To teach undergraduate courses. Preferably under 35. Salary and rank dependent on training and experience. Department of Chemistry and Chemical Engineering, Michigan College of Mining and Technology, Hougton, Michigan.

Chemical Engineering Faculty member needed. Rank and salary dependent upon qualifications. Send résumé and recent photo to: Chairman, Chemical Engineering and Chemistry Departments, Fenn College, Cleveland 15, Ohio.

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Advertisements in the Classified Section are payable in advance at 20¢ a word, with a minimum of four lines accepted. Box number counts as two words. Advertisements average about six words a line. Members of the American Institute of Chemical Engineers in good standing are allowed one six-line Situation Wanted insertion (about 36 words) free of charge a year. Members may enter more than one insertion at half rates. Prospective employers and employees in using the Classified Section agree that all communications will be acknowledged; the service is made available on that condition. Answers to advertisements should be addressed to the box number, Classified Section, Chemical Engineering Progress, 25 West 45th Street, New York 36, N. Y. Telephone COlumbus 5-7330. Advertisements for this section should be in the editorial offices the 15th of the month preceding publication.

(Continued from page 160)

POTENTIAL PLANT MANAGER—likes hard work, incentive salary, making decisions, small growth company, Southern location. Dislikes red-tape, security, hostile unions. Present PVC, styrene processing, seven years'. Organic sythesis production supervision. B.S.Ch.E. 1948, partial M.BA. Box 9-5.

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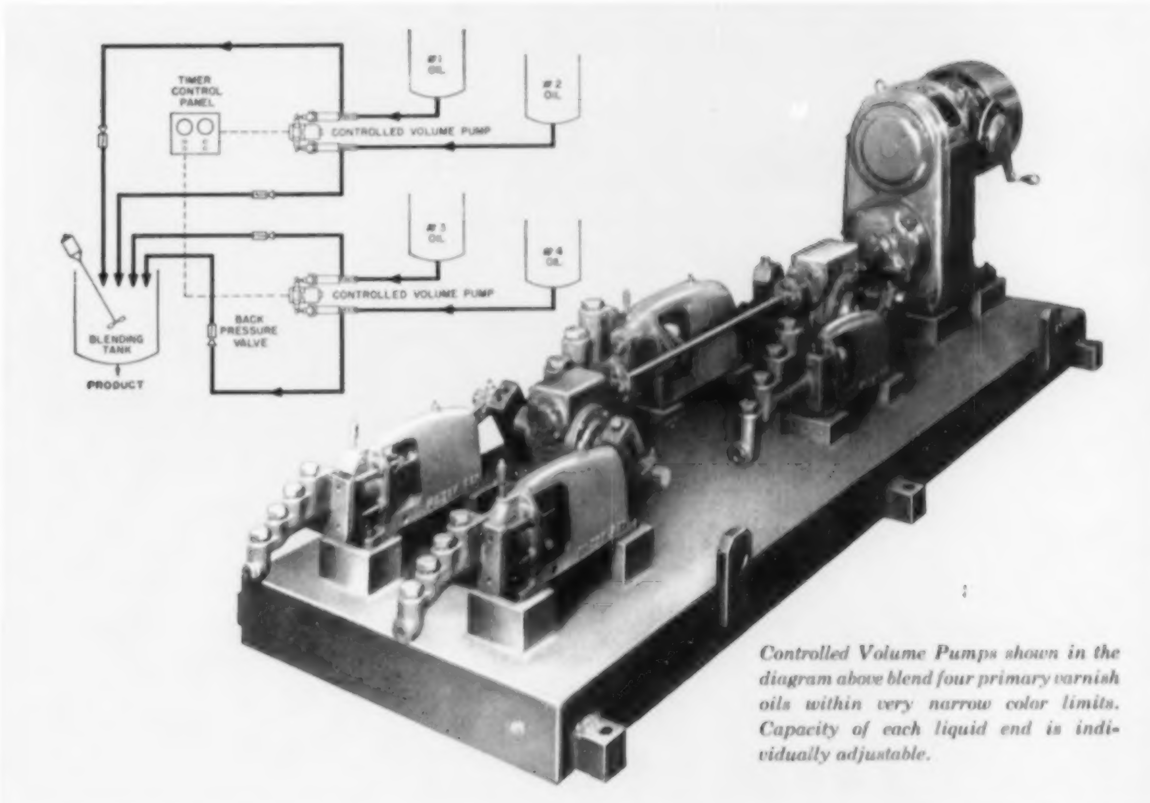
news and notes of A.I.Ch.E.

Council heard recently one of our representatives to United Engineering Trustees, W. E. Lobo, report much progress on **Engineering Center Planning** . . . It has now been definitely decided that the Thirty-ninth Street building will not be revamped but that property will be purchased in New York & a new Engineering Center built . . . There will be roughly five drives: one, a drive to industry headed by the Kelly group . . . second, a drive to members of all the engineering societies, to be spearheaded by a letter & brochure from the president of each society . . . third, a special gifts campaign to individuals who might be in a position to give more than a usual member donation . . . fourth, a campaign to industries & organizations in New York City . . . &, fifth, a campaign inspired by the New York Section when they gave $500 from their treasury to the new building. . . . It is anticipated that other local sections from other points in the United States and from other societies will also contribute funds to this drive . . . . Right now the Real Estate Committee of United Engineering Trustees is in the process of selecting sites in New York City. **Public Relations Committee** reported through R. L. York at White Sulphur Springs on the results of the professional public relations counsel used at the Boston Annual Meeting . . . As was expected, the results were outstanding & the Executive Committee was asked to make a final financial decision for Council on whether professional public relations counsel will be retained permanently . . . Another report from a major committee was heard—that of the **Program** group, which has for some time been studying its own reorganization, the integration of divisions into the Institute & a means of steady growth of the Program group . . . The report, which was the work of the Program Committee Chairman & Vice-chairman, Cotton Coulthurst and Gene Smoley; President Rushton; & an *Ad hoc* Committee of additional members—George Holbrook, W. R. Marshall, D. L. Katz & L. J. Coulthurst—came up with a new plan & schematic of program organization which met with Council's approval. . . . **University of Houston** has a Student Chapter News . . . This first Student Chapter News that I can recall seeing just came to my desk & covers in one sheet the present & future activities of that particular student branch. **The Nominating Committee** has been formed, as noted in the March issue of this column . . . Walter Whitman, past president, is chairman . . . Serving with him this year will be W. B. Franklin of the Humble Oil Company; J. J. Healy, a member of Council & of Monsanto Chemical Company; N. W. Krase of duPont; Jerry McAfee of Gulf Oil Company & another member of Council; H. F. Nolting of Standard Oil Company; E. R. Smoley of the Lummus Company; & R. E. Vivian of the University of Southern California . . . For Local Sections considering sending suggestions to the Nominating Committee or forming a petition, here is the schedule . . . Nominating Committee selections will be made by the week of July 14 & candidates will appear in the August issue of *Chemical Engineering Progress* . . . The first week of October is the latest possible date for candidates' names to be submitted by petition . . . But as was mentioned in the March column, please try to get petitions for candidates in early . . . absolutely no later than July 15 if sufficient publicity is to be given to them in the August issue of *Chemical Engineering Progress.* On the **American Sanitary Engineering Intersociety Board,** of which A.I.Ch.E. is a member, recently elected representatives are Larry Faith, K. L. Swanson, & R. F. Weston.

A memorial fund has been set up in the name of the late **Ernst Berl** by his wife and son . . . Income from the bequest recently contributed to A.I.Ch.E. by Dr. Berl's family will be used in a specific area of student activity . . . As of now it is thought that the income will apply to the student awards given at our annual banquet . . . The idea of the gift stemmed from a memorial dedicated by the friends of Ernst Berl to him at the library of the Technische Hochschule in Darmstadt, Germany . . . Mrs. Berl & her son, remembering the interest Berl had in students, felt that support of a student program of some kind would commemorate his activities in the United States. . . . Above is shown the plaque to Berl in Darmstadt. F.J.V.A.



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